



ADVANCING OCEAN DATA ASSIMILATION AT NCEP

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SUMMARY



- The Hybrid-GODAS
 - OSSE experiments
 - 21-year Ensemble Reanalysis
-

THE HYBRID-GAIN 3DVAR/LETKF

Penny, S.G., 2014: The Hybrid Local Ensemble Transform Kalman Filter. Mon. Wea. Rev., 142, 2139–2149.

$$K^P = P^b H^T (H P^b H^T + R)^{-1} \quad \text{LETKF Gain}$$

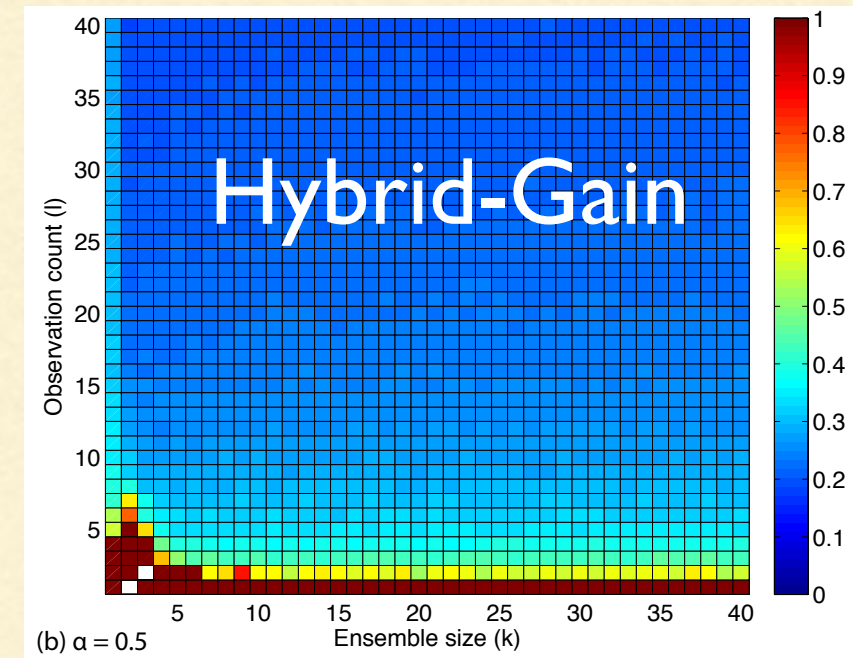
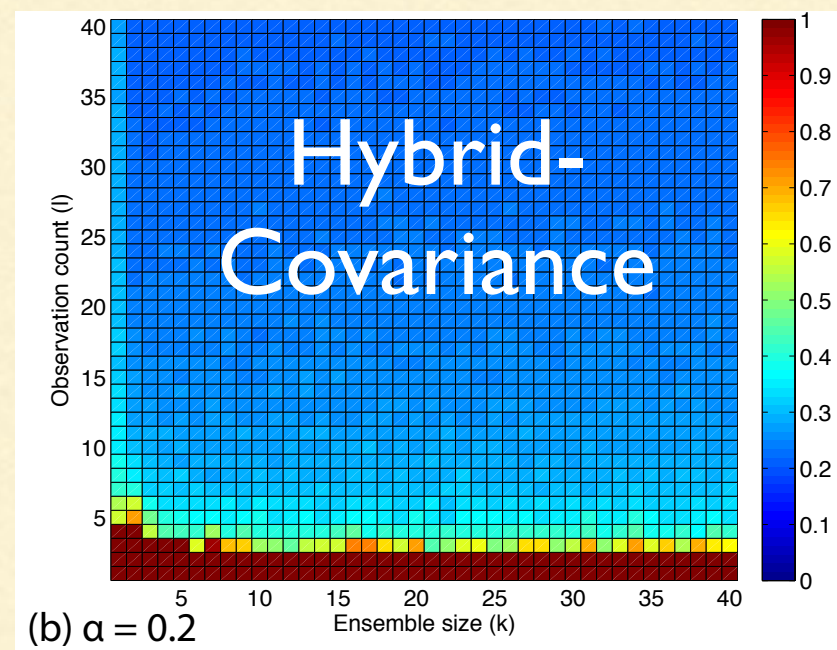
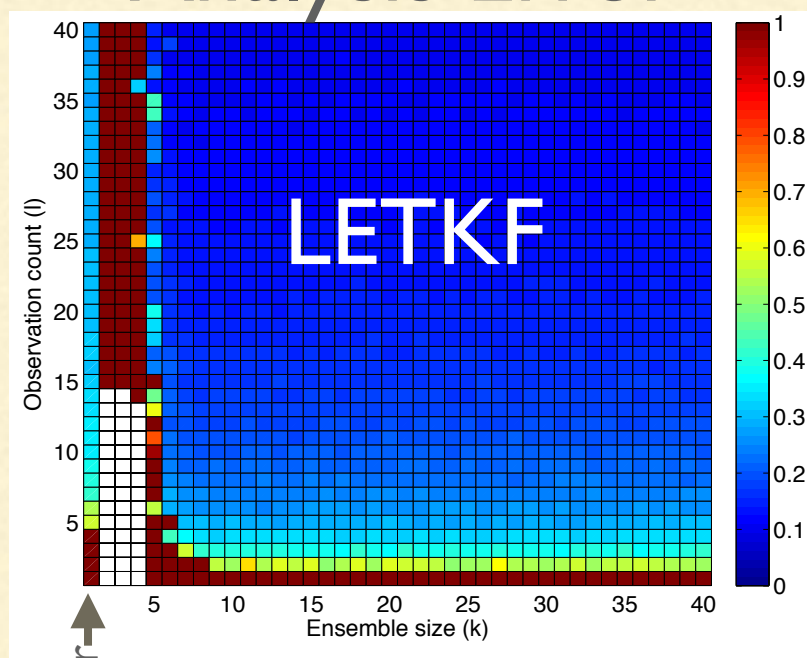
$$K^B = B H^T (H B H^T + R)^{-1} \quad \text{3DVar Gain}$$

Adaptive
contraction
↓

$$K = K^P + \alpha K^B - \alpha K^B H K^P = K^P + \alpha K^B [I - H K^P]$$

Analysis Error

Observation Count



Ensemble Size

Lorenz-96 system

HYBRID-GODAS

Penny, S.G., D. Behringer, J. Carton, E. Kalnay, 2015: A Hybrid Global Ocean Data Assimilation System at NCEP. Mon. Wea. Rev., (Submitted for publication).

- The current system uses GFDL's MOM4p1 (1/2x1/4°) (LETKF is currently compatible with MOM versions 4,4p1,5,6)
 - Localization is applied in the horizontal with 700km sigma-radius at the equator, decreasing to 200km at the poles.
 - No localization is applied in the vertical, analysis weights are applied equally throughout all depths.
 - Analysis variables: Temperature, Salinity, U/V velocities
 - Currently assimilating:
 - ☒ Temperature Profiles
 - ☐ SST
 - ☐ SSH
 - ☒ Salinity Profiles
 - ☐ SSS
 - ☐ Ocean Color
-

OBSERVING SYSTEM SIMULATION EXPERIMENT (OSSE)

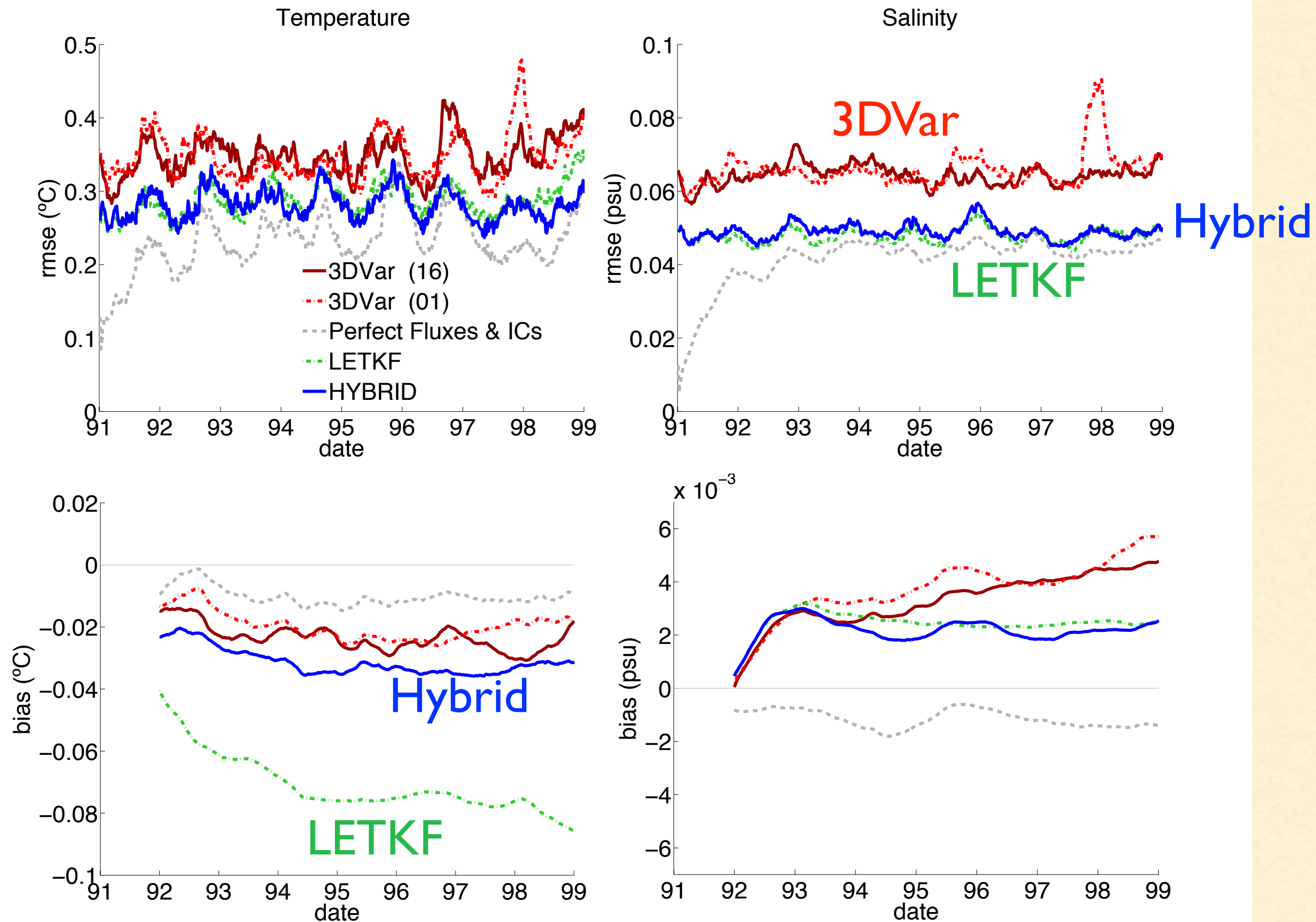
<u>Experiments:</u>	<u>Ens. Size:</u>	<u>Forcing:</u>	<u>Imposed Bias:</u>
• Nature	1	R2	none
• 'Perfect' 3DVar	1	R2	none
• 3DVar	1	1 and 16	R2 vs. 1, R2 vs. 16
• LETKF	28	1-28	R2 vs. <1-28>
• Hybrid	28	1-28	R2 vs. <1-28>

Surface forcing *perturbations* come from a subsampling of the 56 members from the 20th Century Reanalysis (20CR)

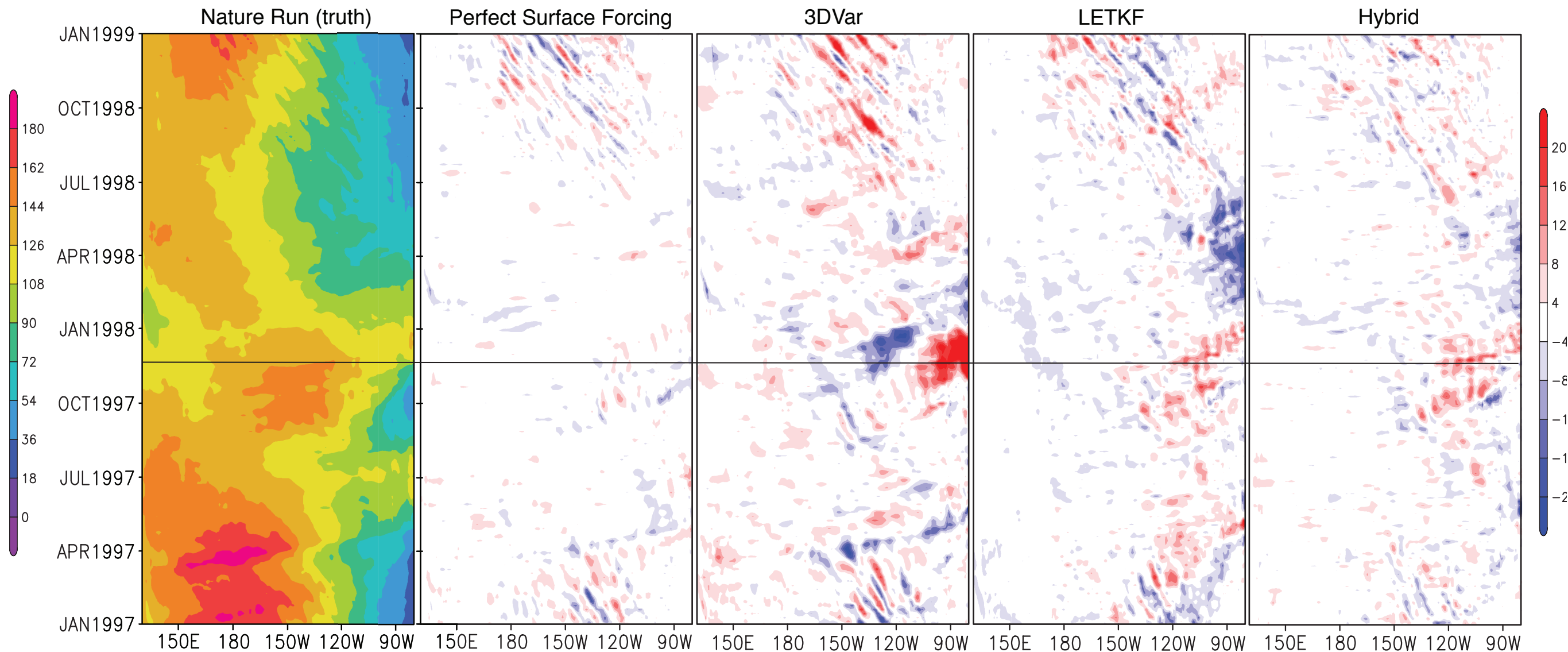
Observations locations match the observations used in the Climate Forecast System Reanalysis (CFSR)

Observation errors are identical between all DA experiments

OSSE Results: RMSE and BIAS

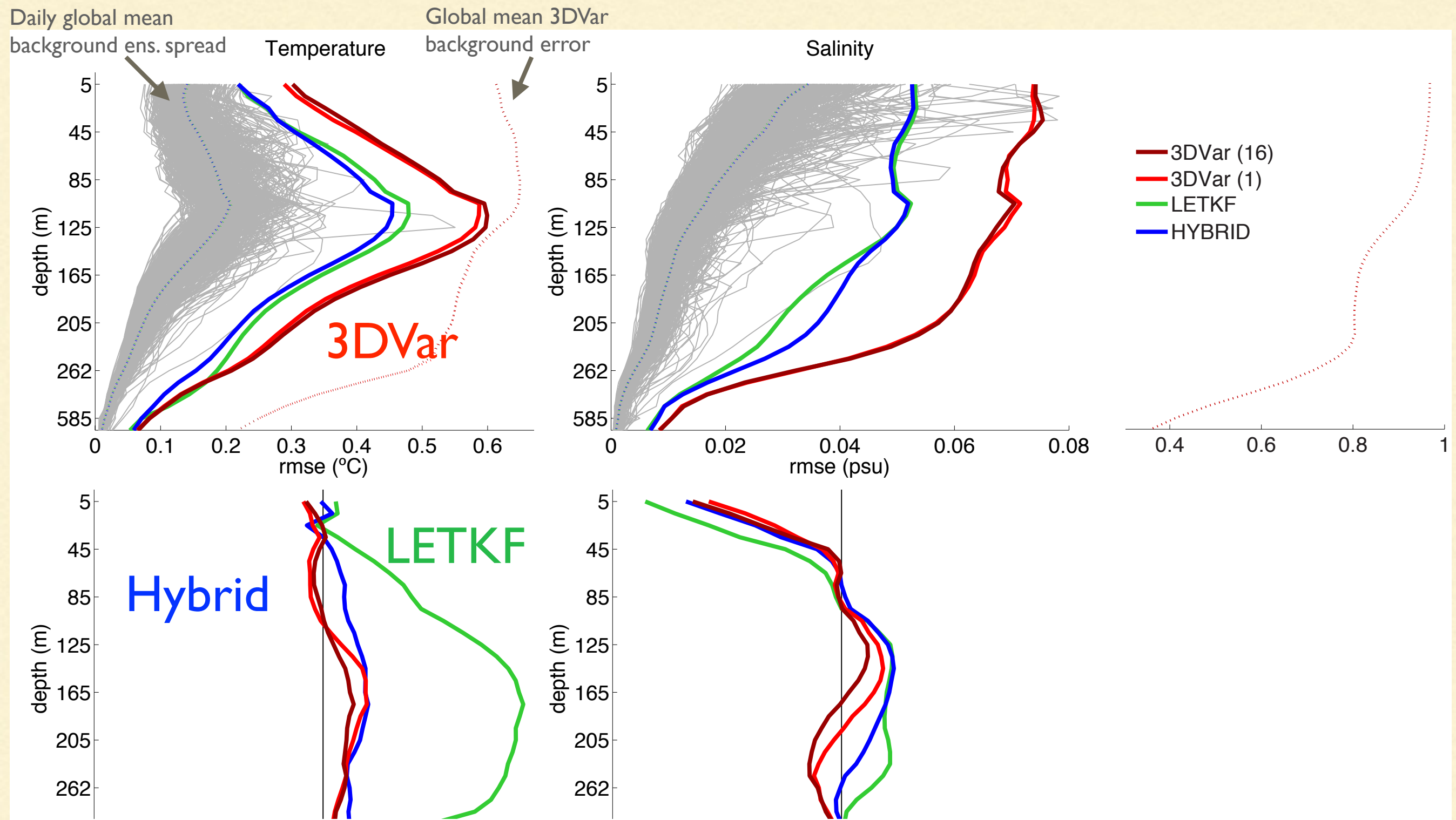


OSSE Results: Error in the 20°C Isotherm Depth



The Hybrid-GODAS generally reduces errors where there is disagreement between 3DVar and LETKF

OSSE Results: RMSE vs. background spread and BIAS in upper ocean



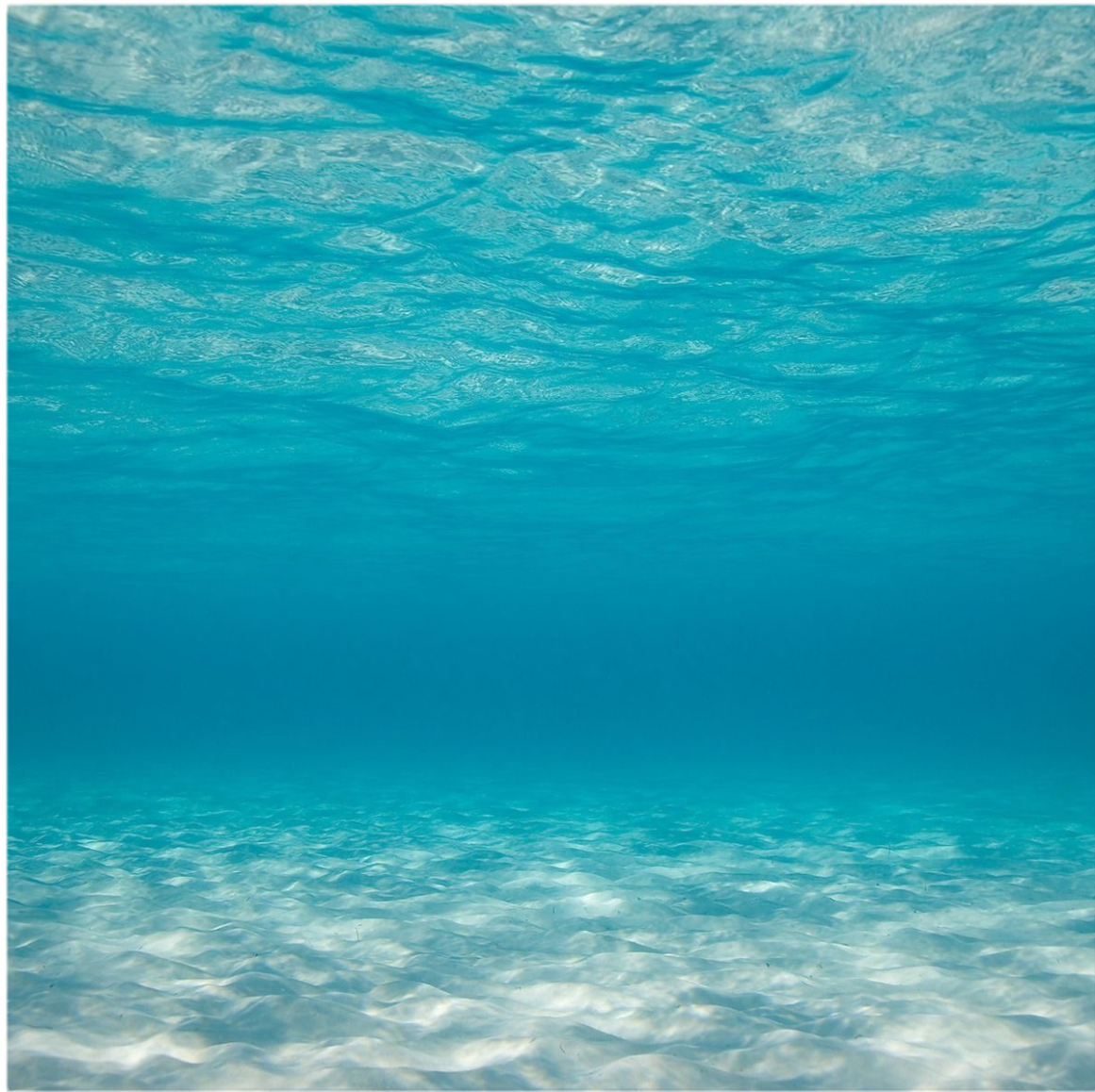
The bias imposed on LETKF via surface forcing is reduced with the Hybrid

OSSE SUMMARY



- Ensemble approaches reduced RMSE of forecast and analysis errors vs. 3DVar
- The Hybrid reduced biases imposed on LETKF via surface forcing conditions

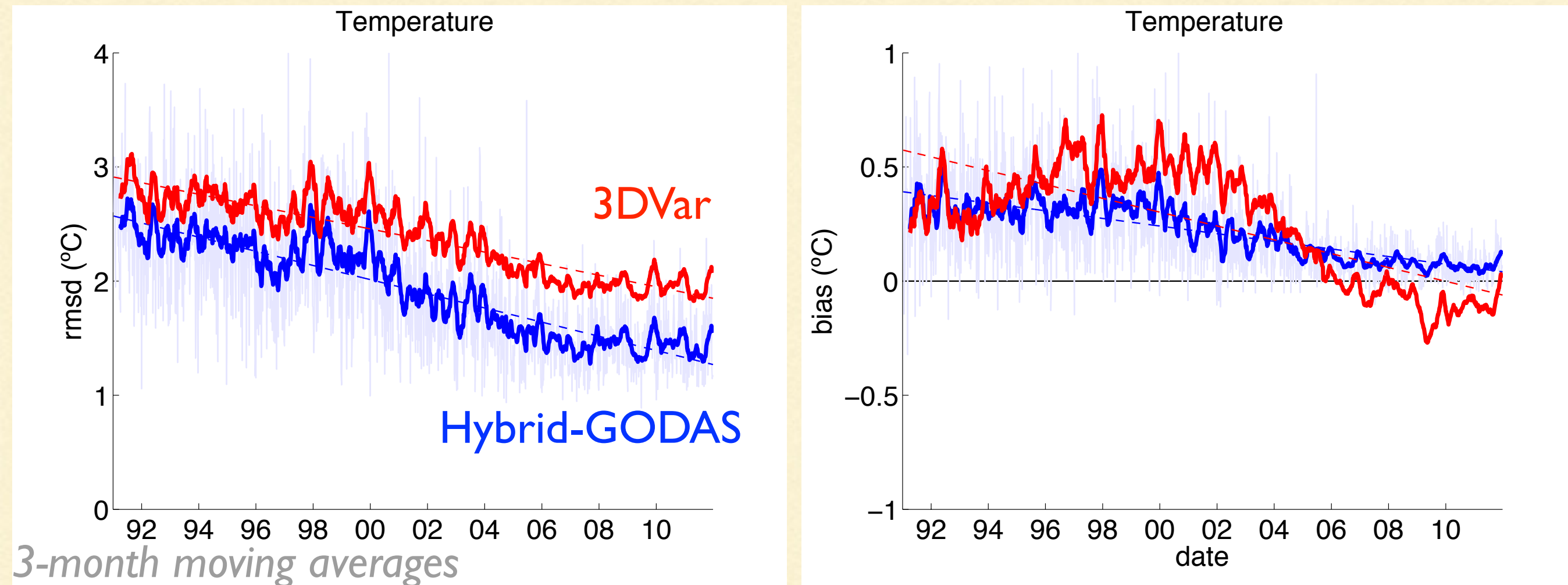
21-YEAR REANALYSIS (1991-2011)



- Observation data mirrors the CFSR (T/S Profiles: XBT, TAO/TRITON, ARGO, etc.)
- 56-members, surface fluxes centered at R2 with perturbations from 20CR (T62)
- The LETKF component does *not* use synthetic salinity.
- The 3DVar component *does* use synthetic salinity.
- The following results show Hybrid-GODAS vs. 3DVar-GODAS using identical models, observations, and observation errors.

21-Year Reanalysis Results (1991-2011)

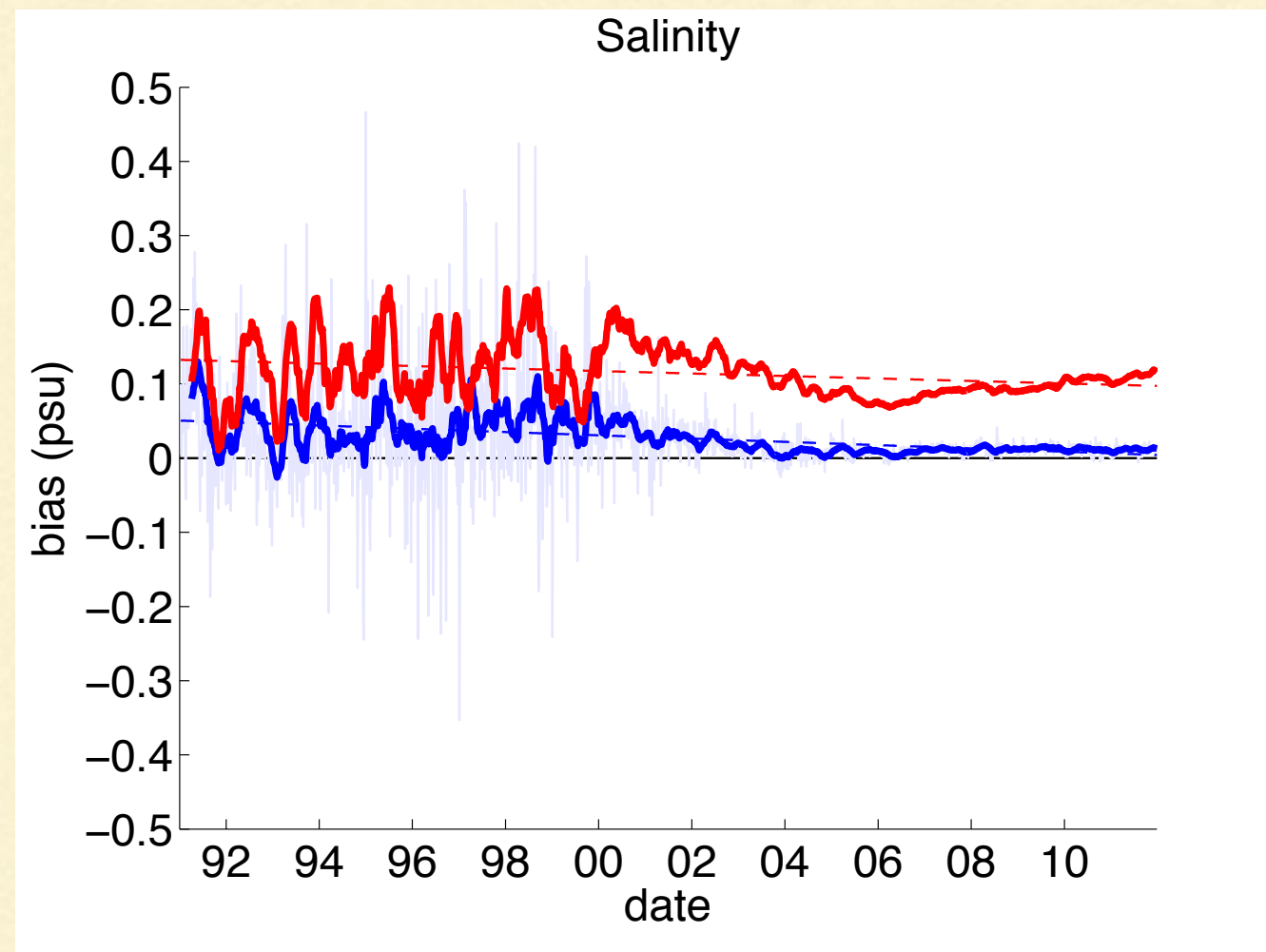
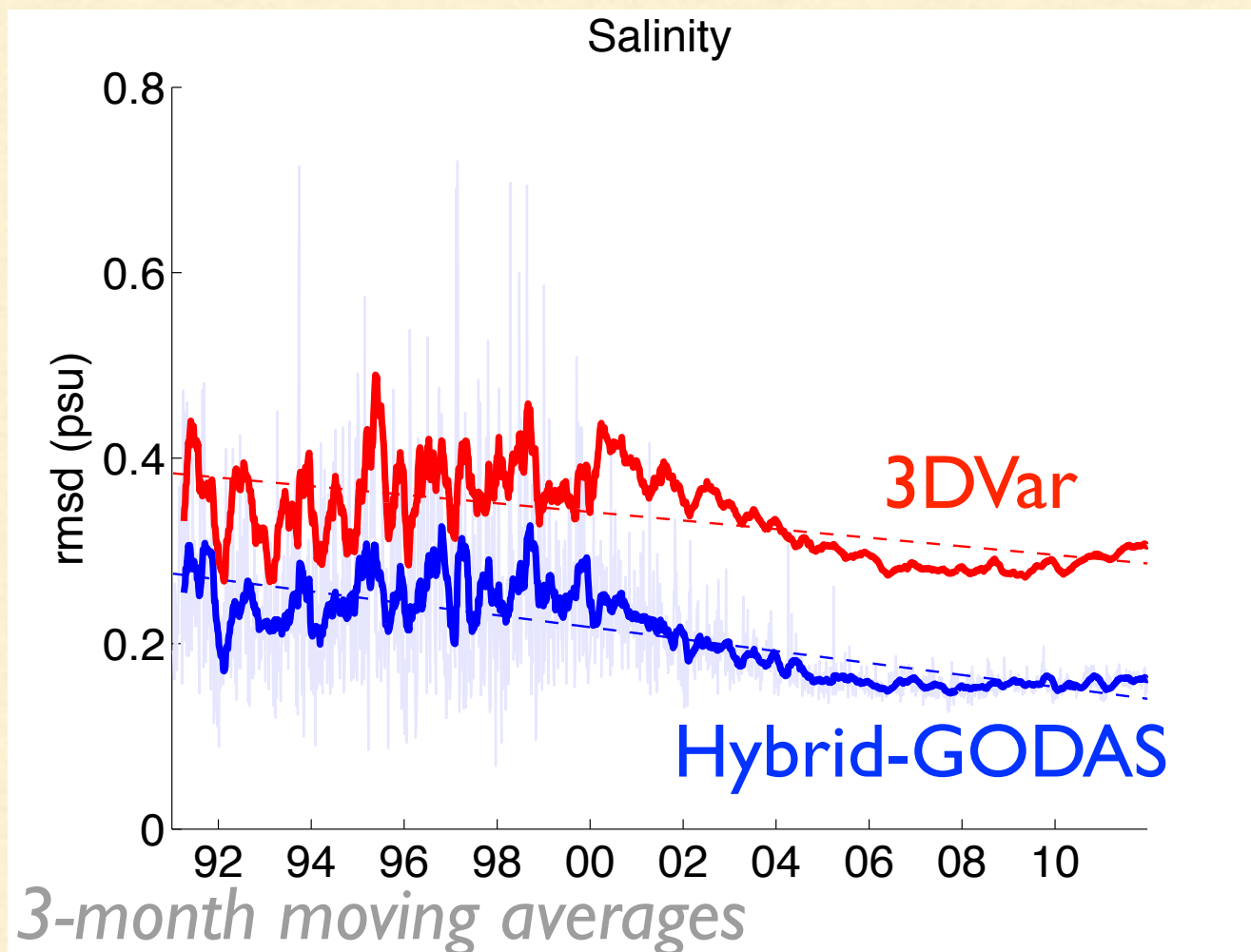
OBSERVED-MINUS-FORECAST GLOBAL RMSD AND BIAS (0-700M)



Temperature (O-F) RMSD and BIAS reduced
using the Hybrid-GODAS (5-day forecasts)

21-Year Reanalysis Results (1991-2011)

OBSERVED-MINUS-FORECAST GLOBAL RMSD AND BIAS (0-700M)



Salinity (O-F) RMSD and BIAS reduced
using the Hybrid-GODAS (5-day forecasts)

21-YEAR REANALYSIS (1991-2011)



- Remaining results show the Hybrid-GODAS vs. the Operational GODAS
- The operational GODAS uses:
 - MOM3, with $1 \times 1/3^\circ$ resolution
 - 3DVar with repeatedly reused observations, and assimilation of altimetry since 2007
- Comparisons are made to Altimetry and the Met Office EN4 monthly objective analysis

Purpose: Indicate impacts of Hybrid on monthly to seasonal timescales

CORRELATION WITH ALTIMETRY

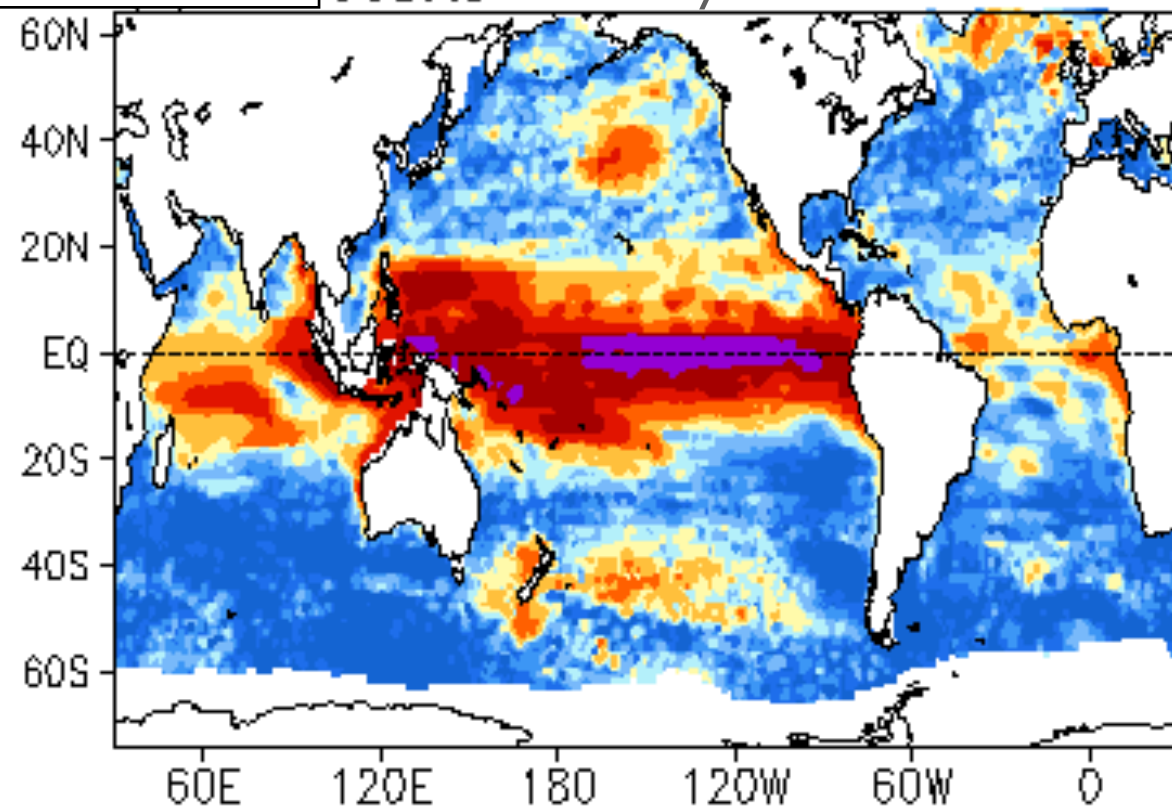
A summary of improvements over the operational 3DVar-GODAS:

- Hybrid-GODAS sea level Anomaly Correlations (ACs) are generally improved across the global ocean.
 - Sea level ACs and Root Mean Square Deviations (RMSDs) are improved particularly in the Tropical Pacific, Equatorial Atlantic, Southern Pacific, Southern Atlantic, and in the Southern Indian Ocean
-

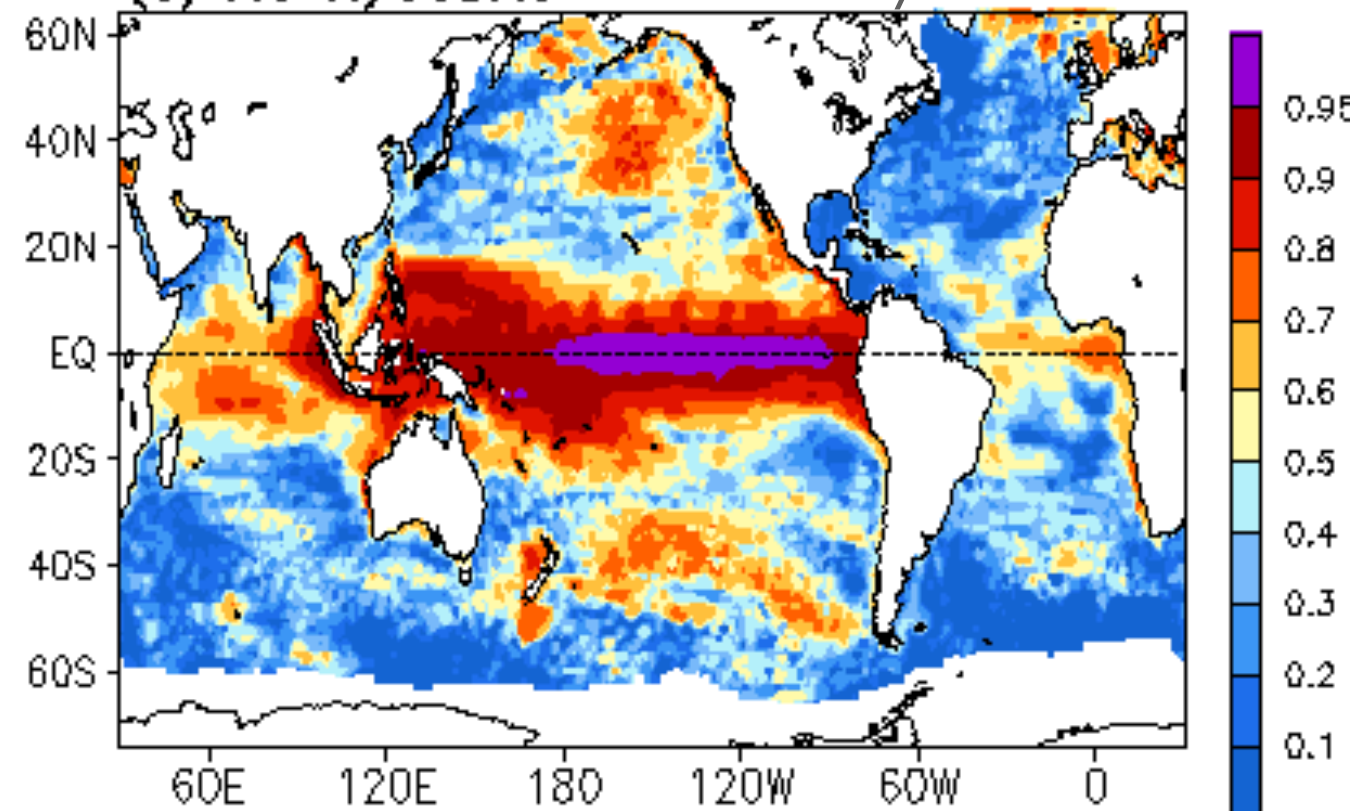
Comparison with Altimetry SSH (1995-2011)

Anomaly
Correlation

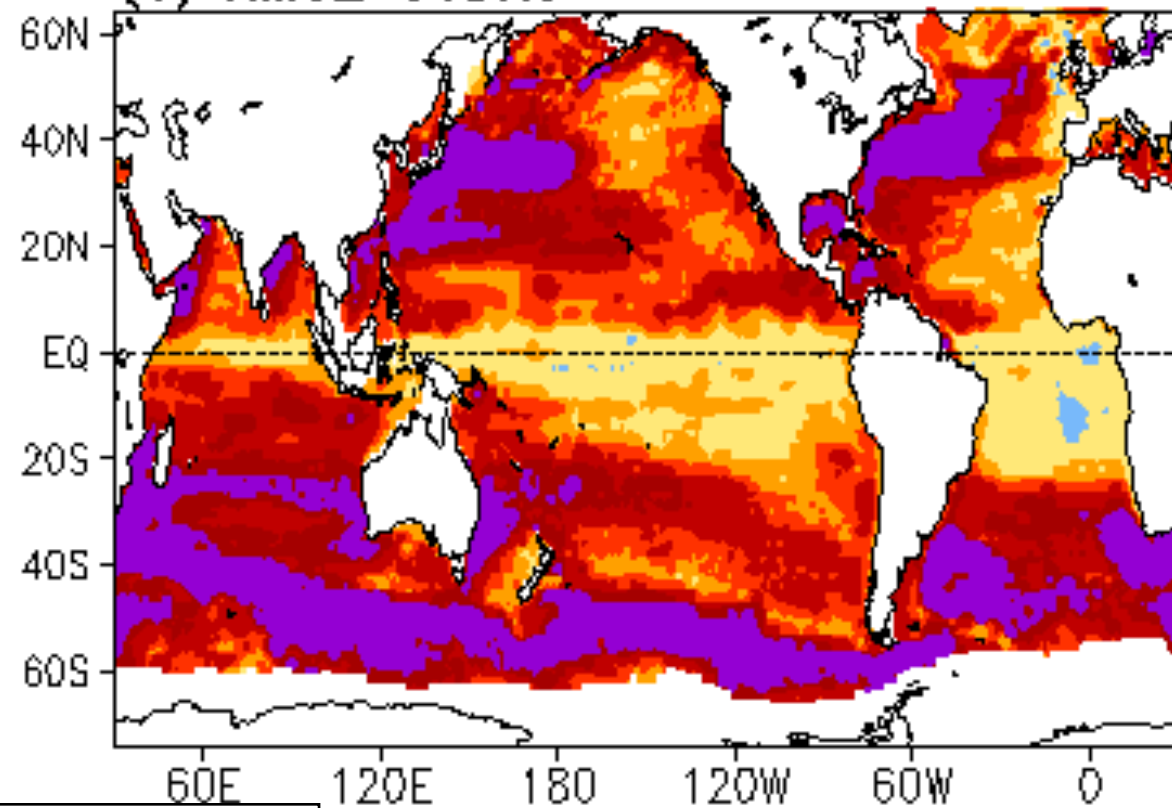
GODAS Altimetry assimilated 2007-2011



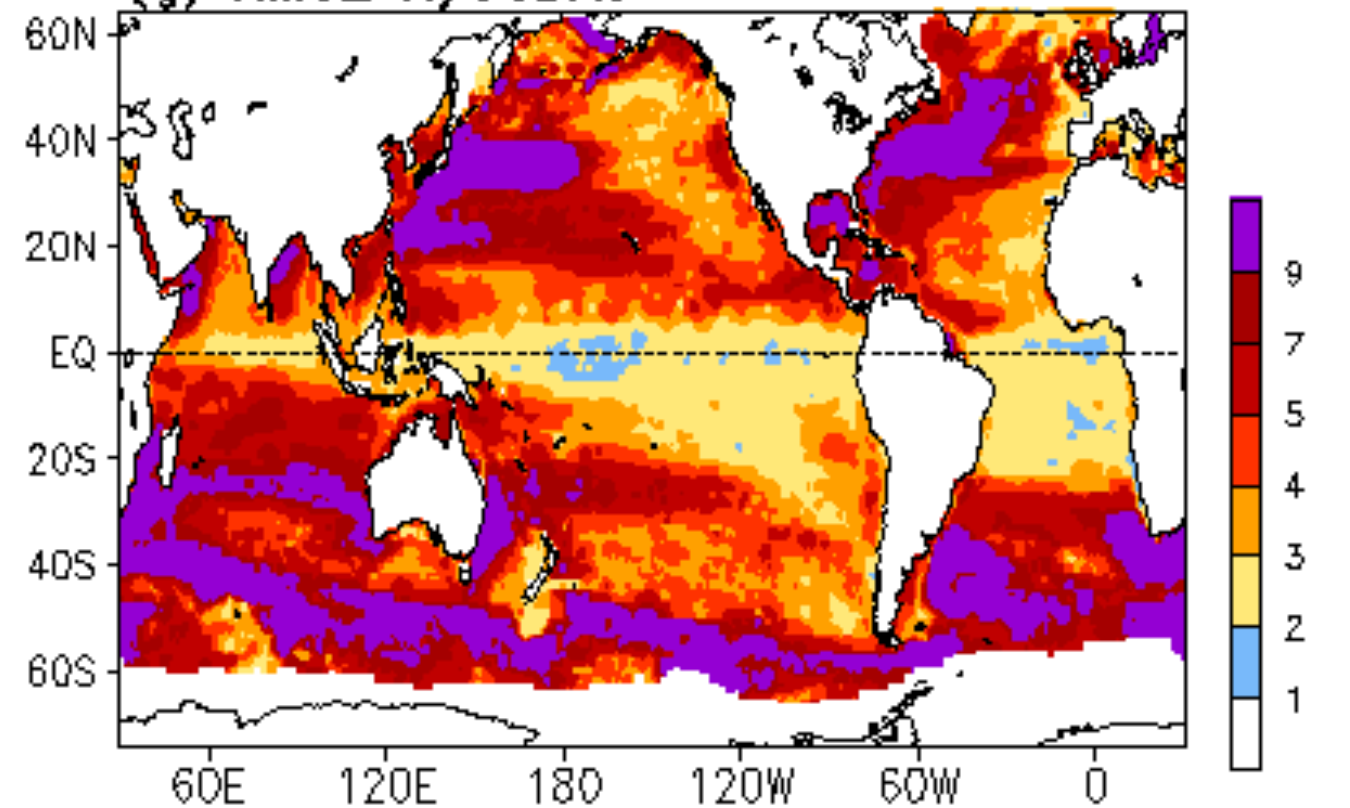
(c) AC HyGODAS No Altimetry assimilated



(e) RMSE GODAS



(g) RMSE HyGODAS



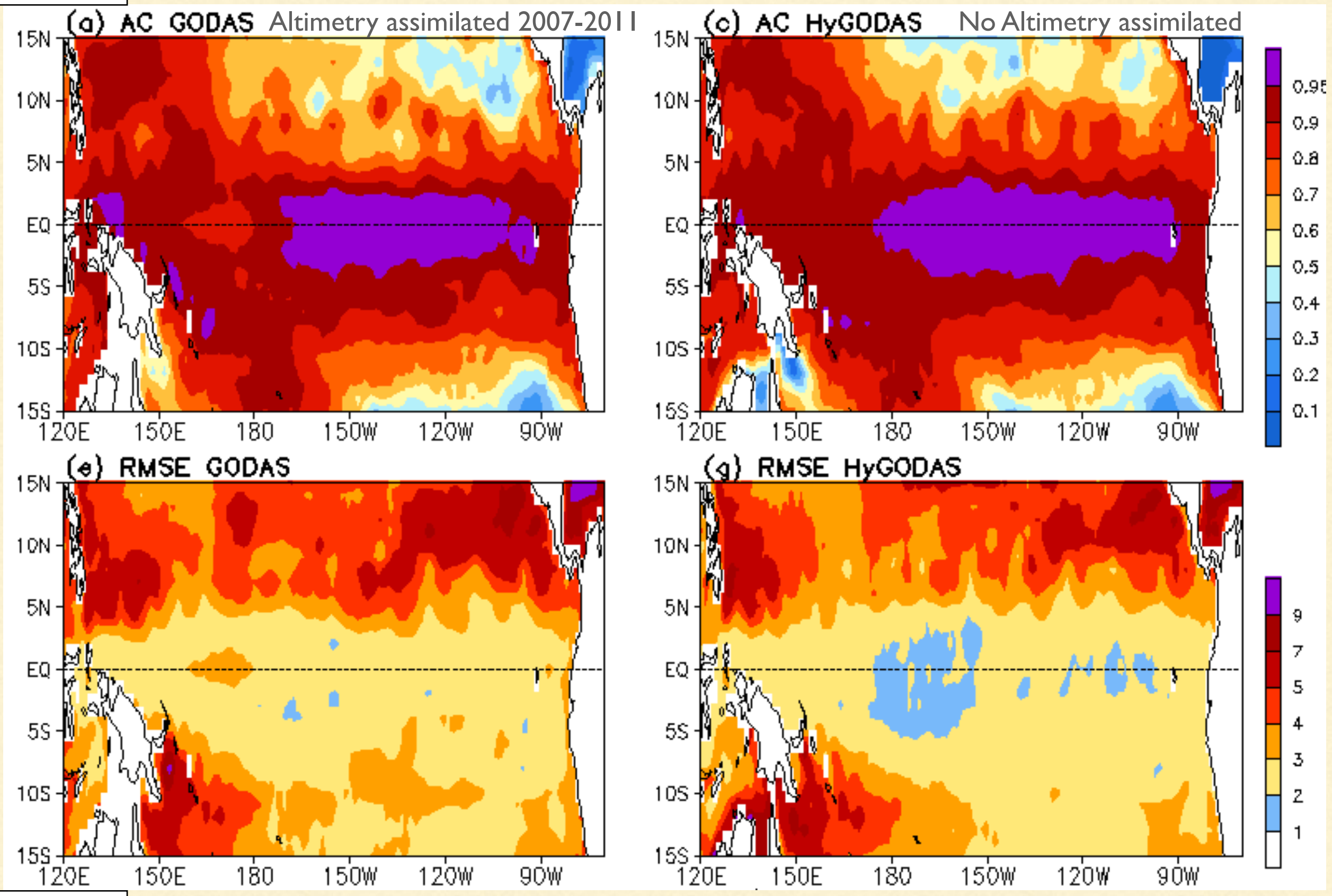
RMSE

Plots provided by Yan Xue

Anomaly
Correlation

Comparison with Altimetry SSH (1995-2011)

Focus: Tropical Pacific



RMSE

Plots provided by Yan Xue

SEA SURFACE SALINITY (SSS)

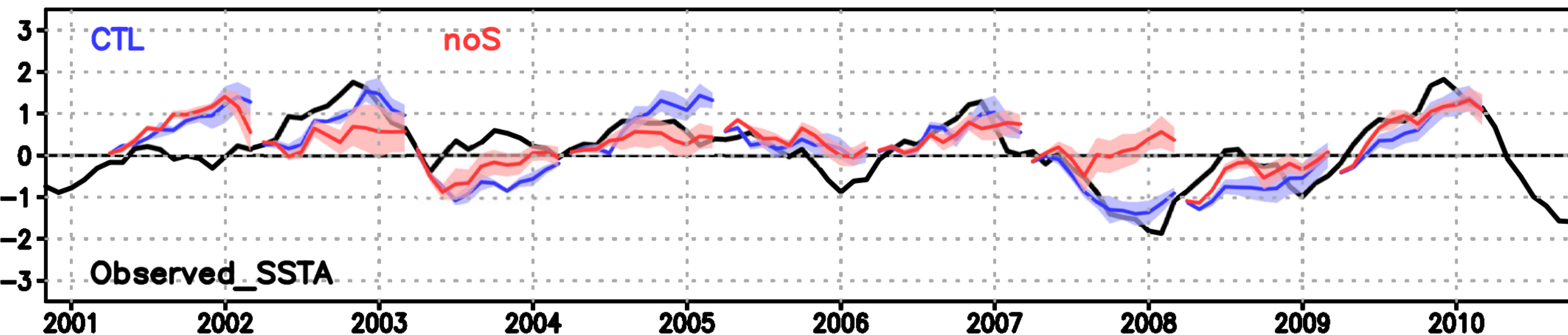
Summary of improvements over the operational 3DVar-GODAS compared to EN4 monthly analysis:

- Hybrid-GODAS captures the ENSO cycle in Equatorial Pacific SSS
 - Anomaly Correlations (ACs) in SSS and upper ocean salinity are increased throughout most of the global ocean
 - Root Mean Square Deviations (RMSDs) of SSS are reduced throughout most of the global ocean
 - RMSDs of upper ocean salinity (S300) are reduced in the Tropical Pacific and Southern Ocean
 - RMSDs of S300 are increased in the Pacific extra-tropics and equatorial Atlantic
-

SEA SURFACE SALINITY AND EL NIÑO PREDICTABILITY

“...in addition to the passive response, **salinity variability** may also **play an active role in ENSO evolution**, and thus important in forecasting El Niño events. By comparing two forecast experiments in which the interannual variability of salinity in the ocean initial states is either included or excluded, the salinity variability is shown to be essential to correctly forecast the 2007/08 La Niña starting from April 2007.”

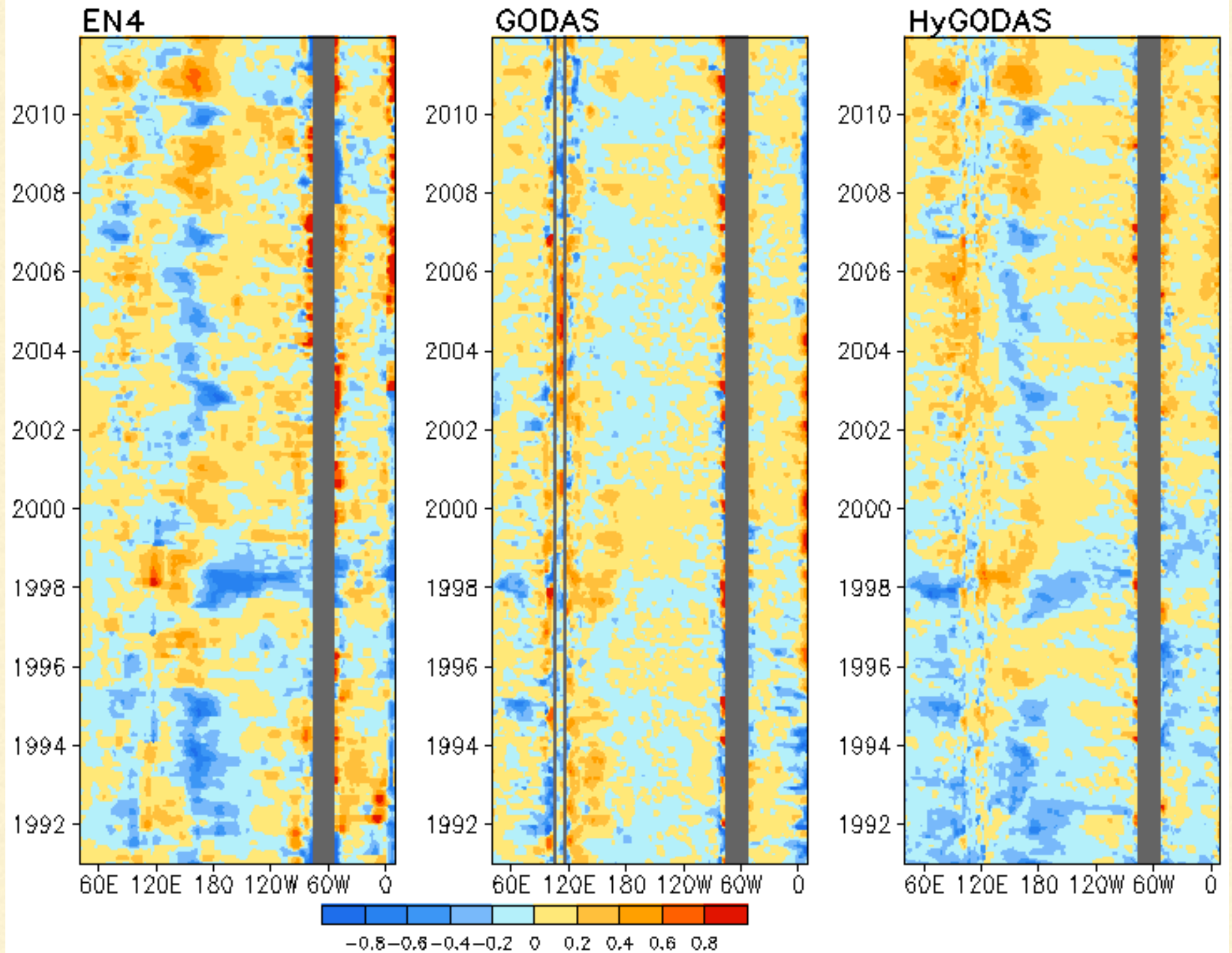
Predicted and observed Nino-3.4 index: 2001–2009



Niño-3.4 SST anomalies (2001-2010) for observations (black), CTL (blue) and noS (red). Solid curves represent the forecast ensemble mean, and shaded areas the forecast ensemble spread.

Sea Surface Salinity (5m) Anomaly, (psu) 5°S-5°N

HYBRID-
GODAS
captures the
ENSO cycle
in Tropical
Pacific SSS

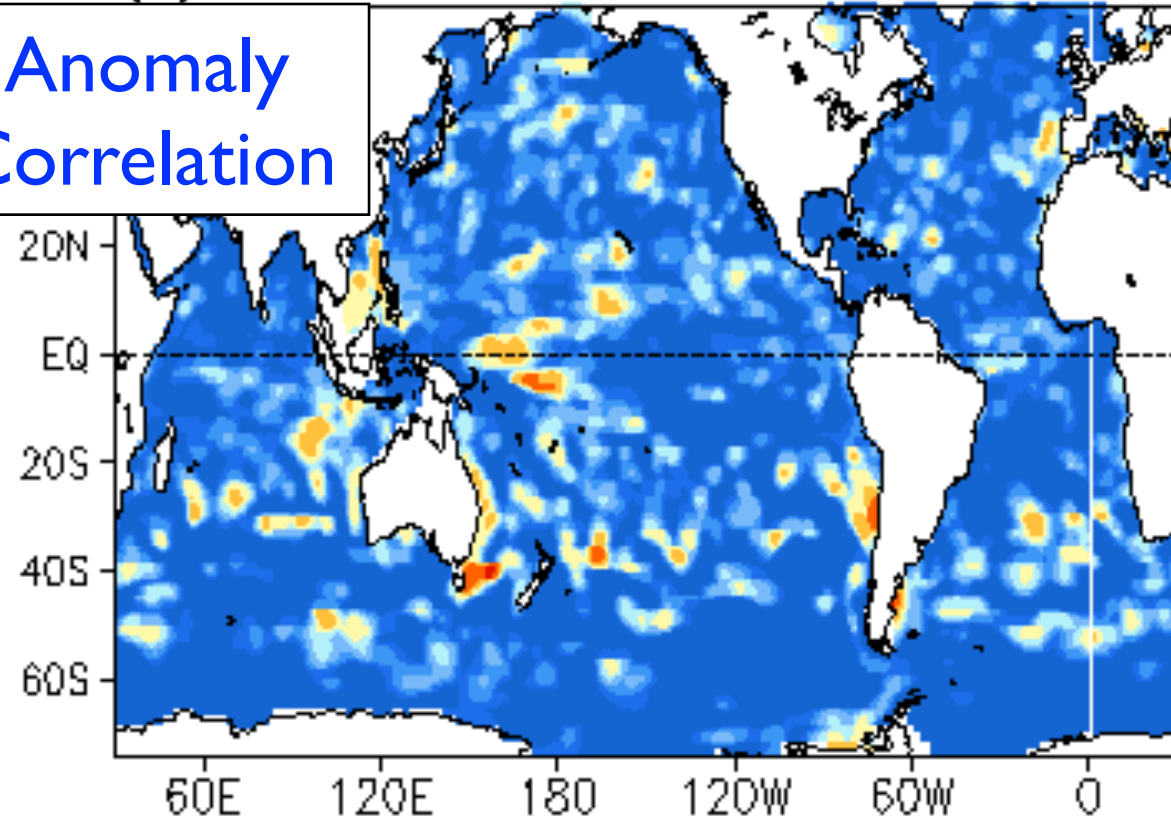


Plots provided by Yan Xue

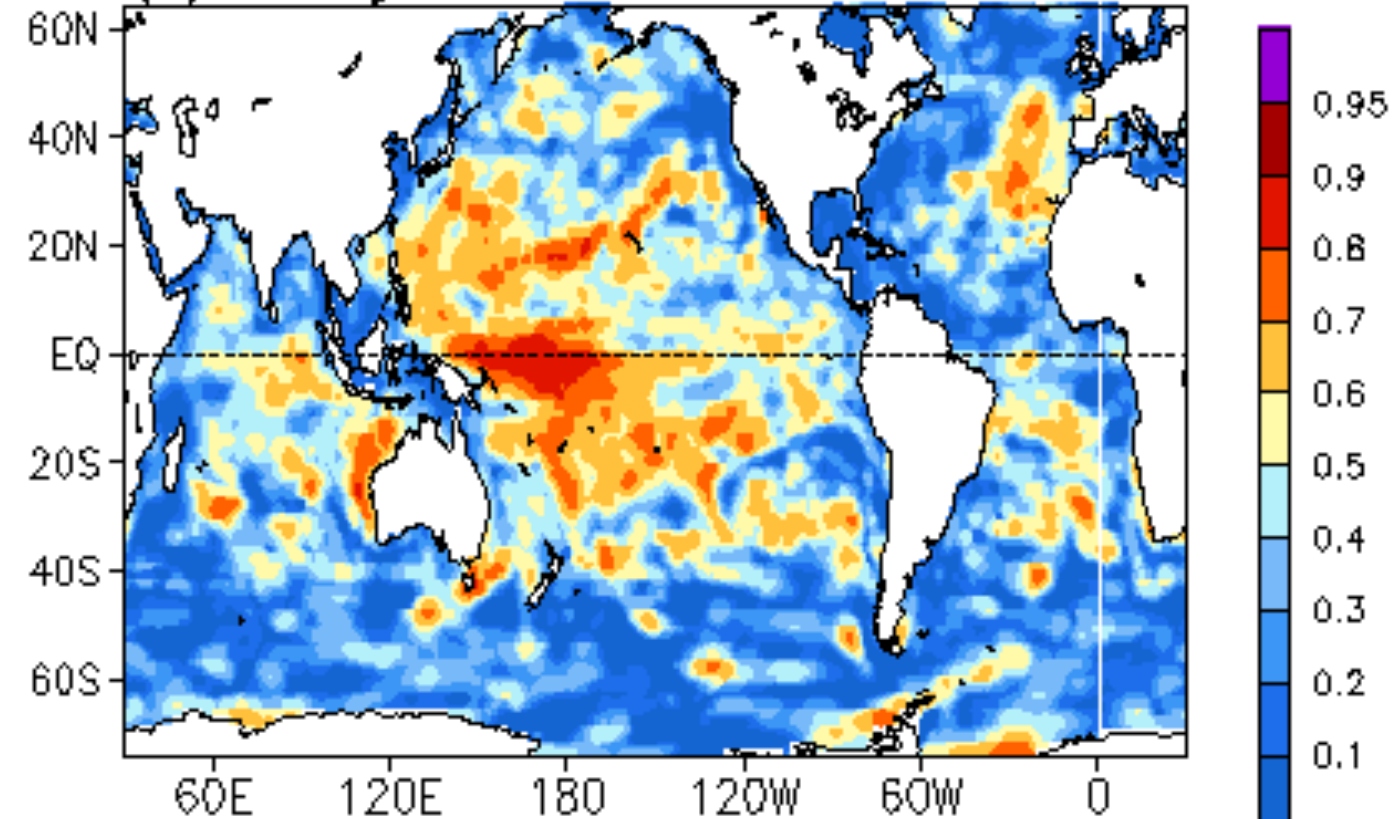
Comparison with EN4 Sea Surface Salinity at 5m, 1995-2011

(a) AC GODAS

Anomaly
Correlation

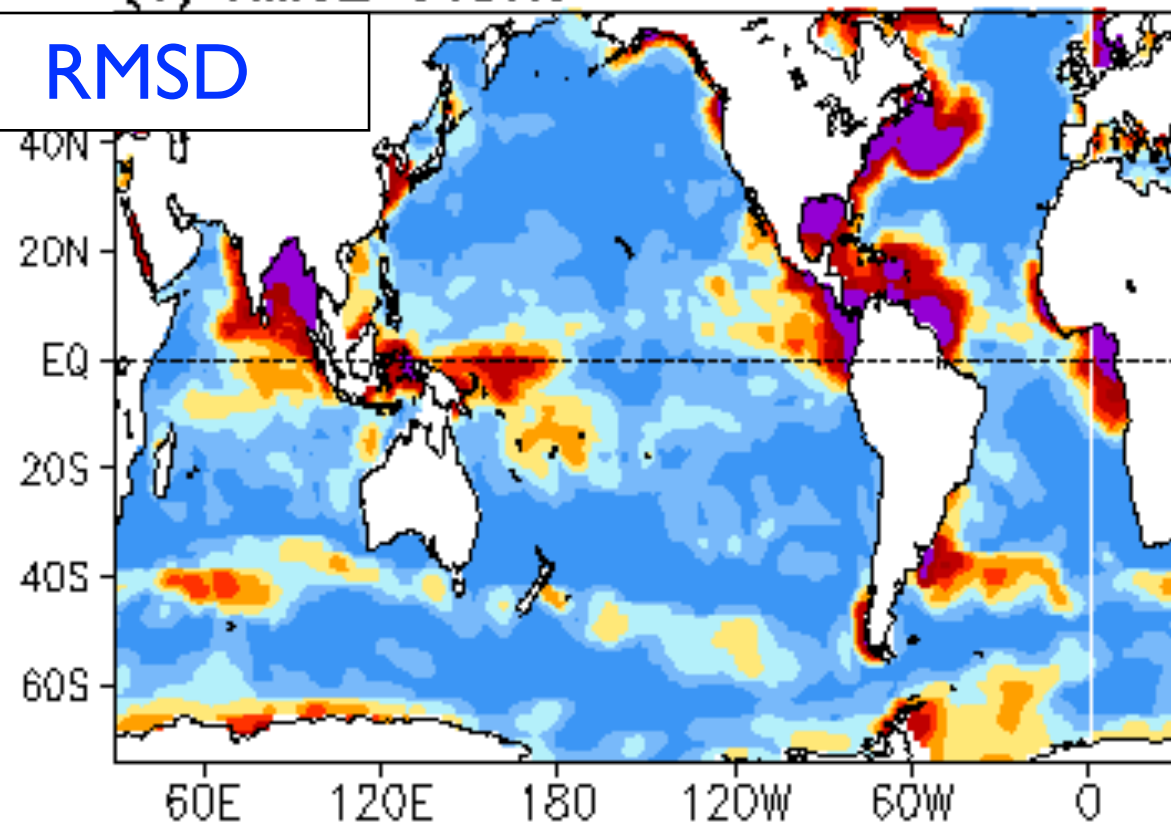


(c) AC HyGODAS

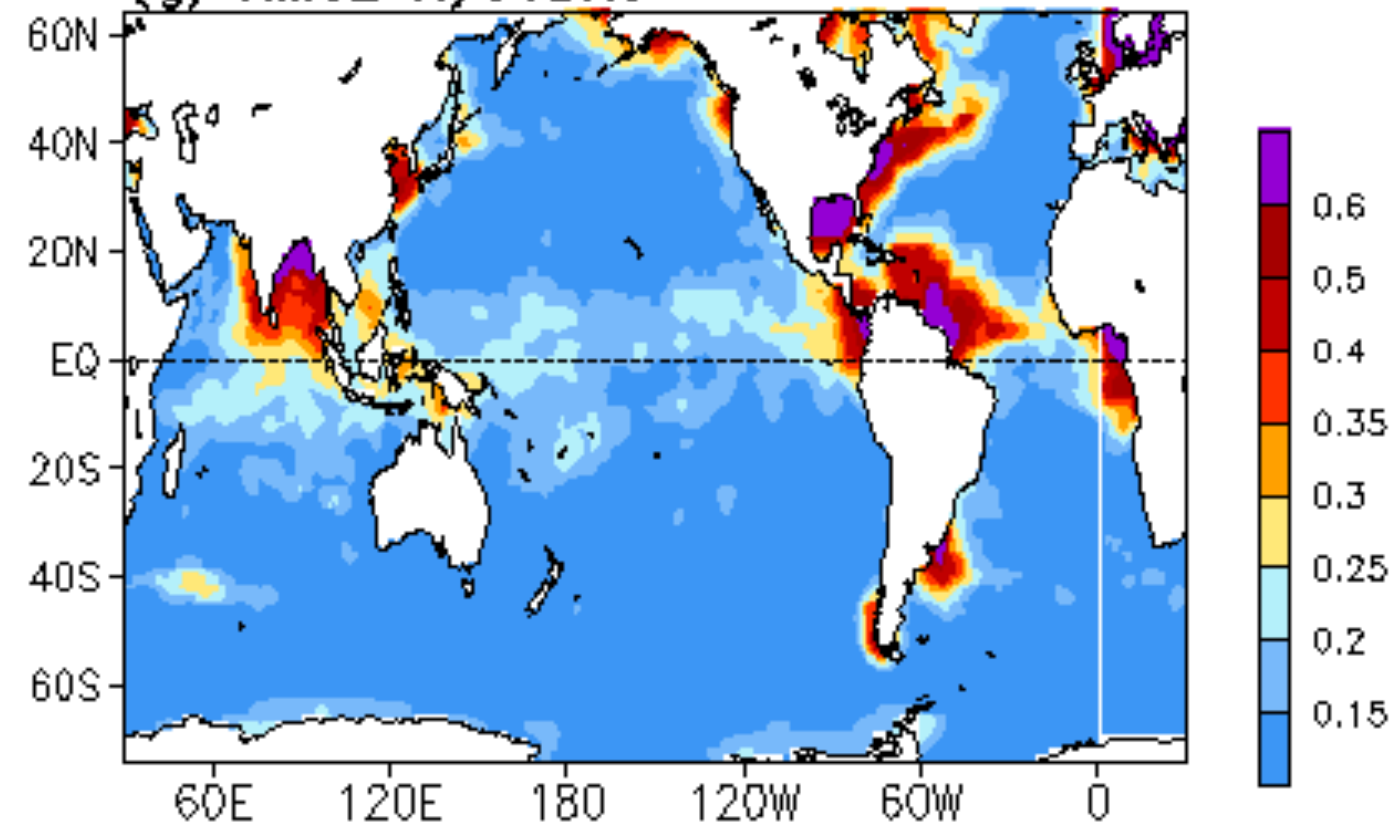


(e) RMSE GODAS

RMSE



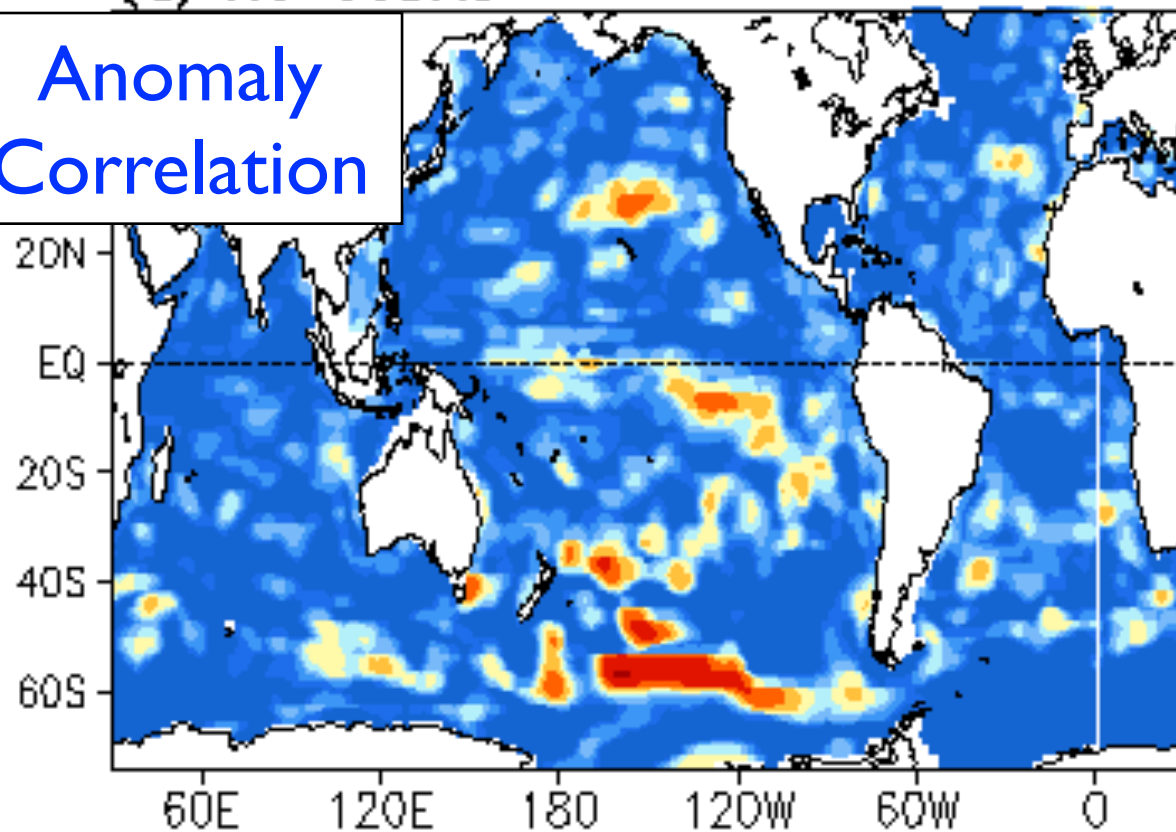
(g) RMSE HyGODAS



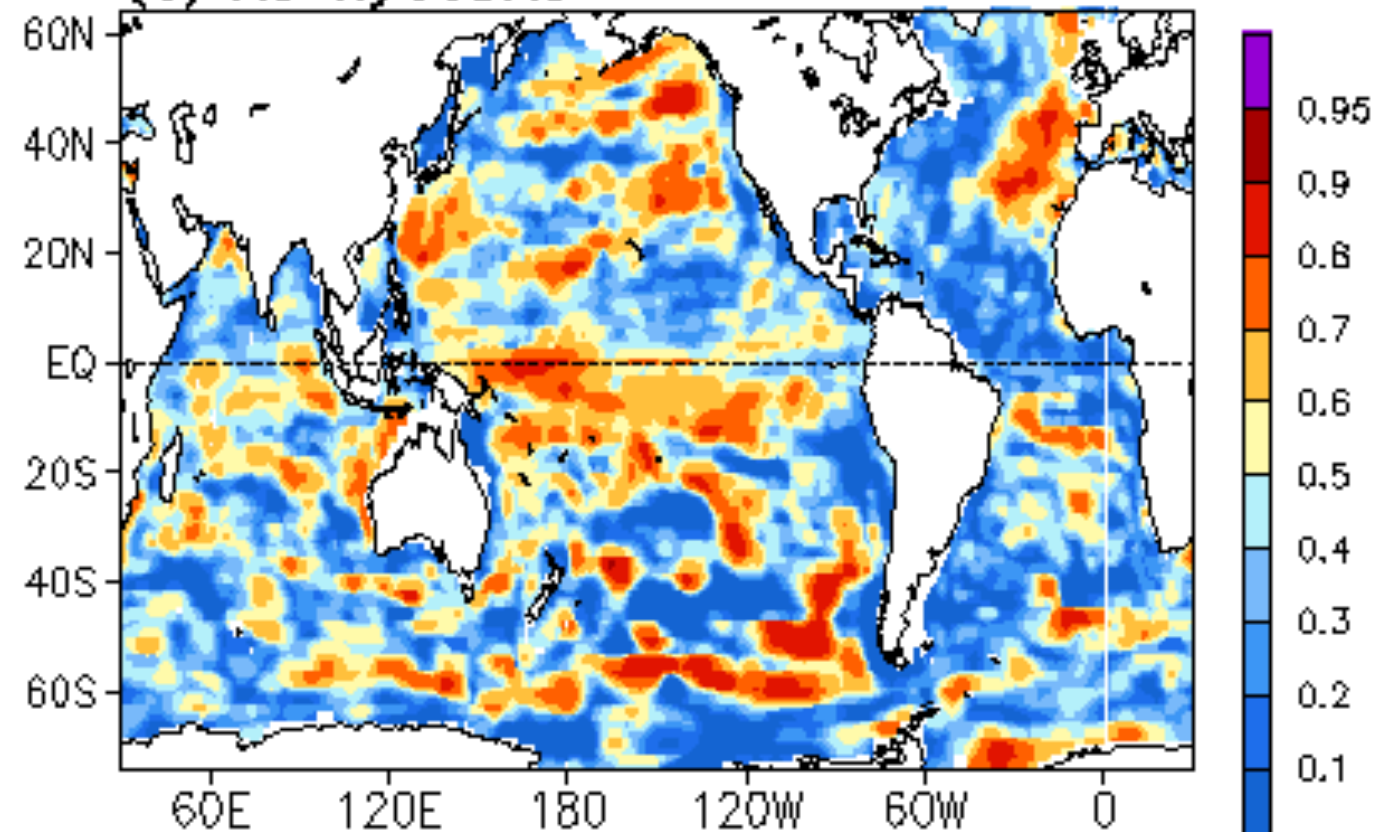
Comparison with EN4 S300, (1995-2011)

(a) AC GODAS

Anomaly
Correlation

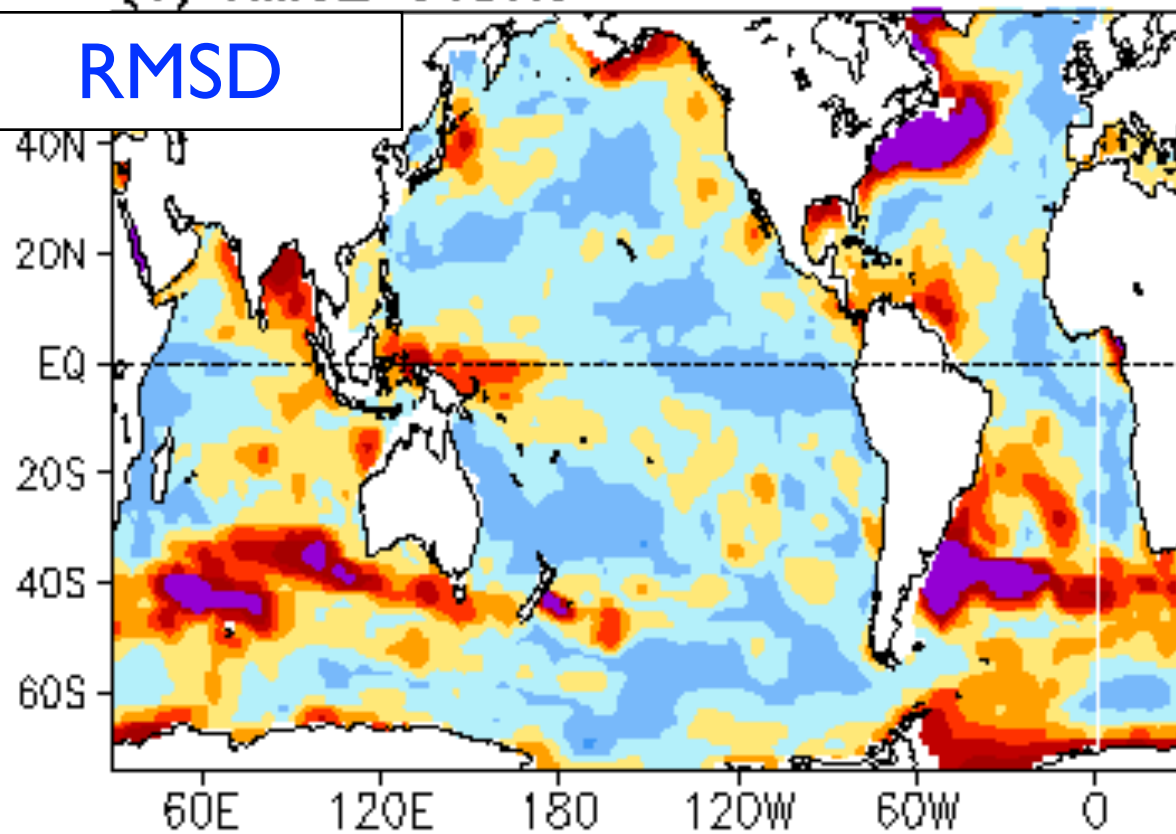


(c) AC HyGODAS

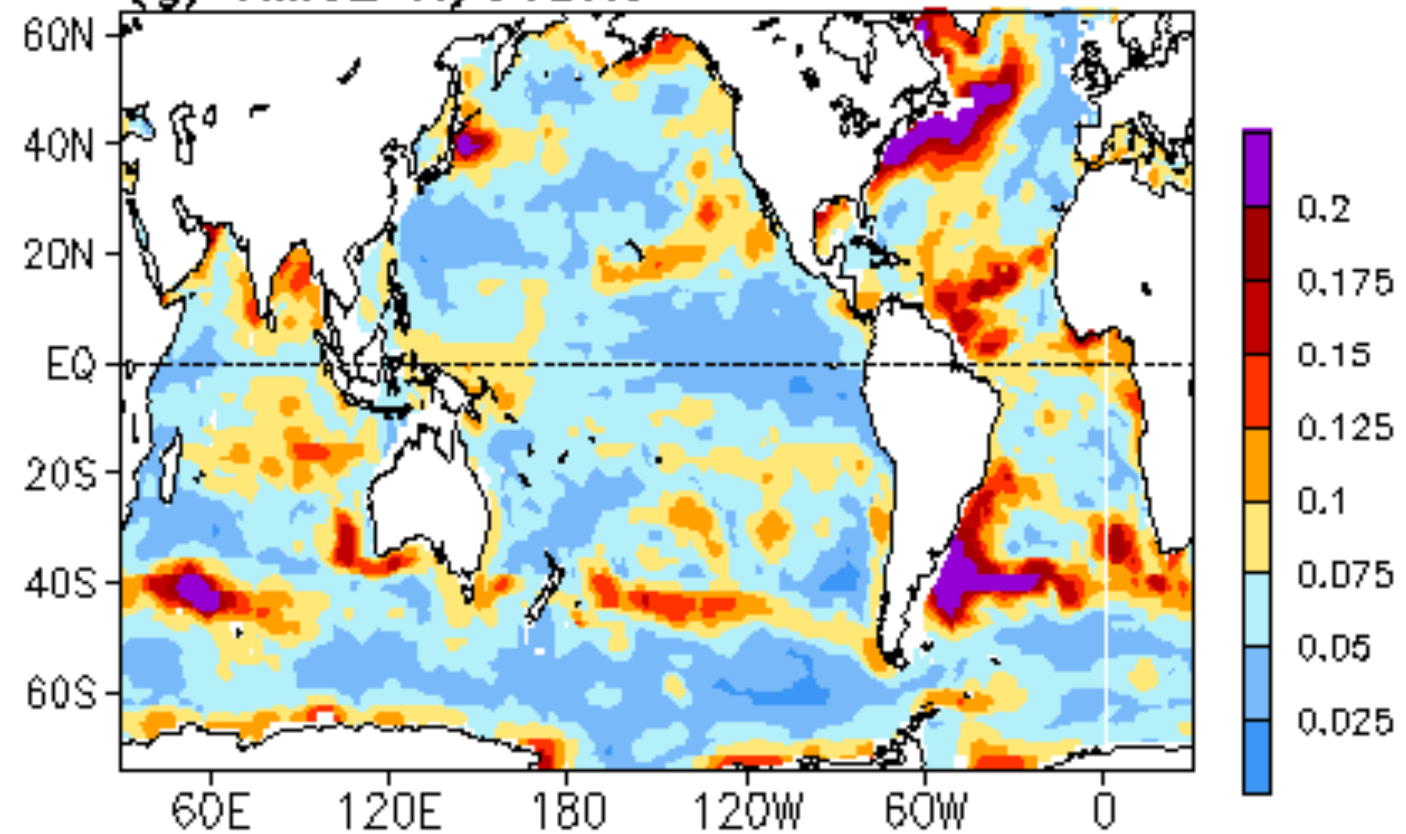


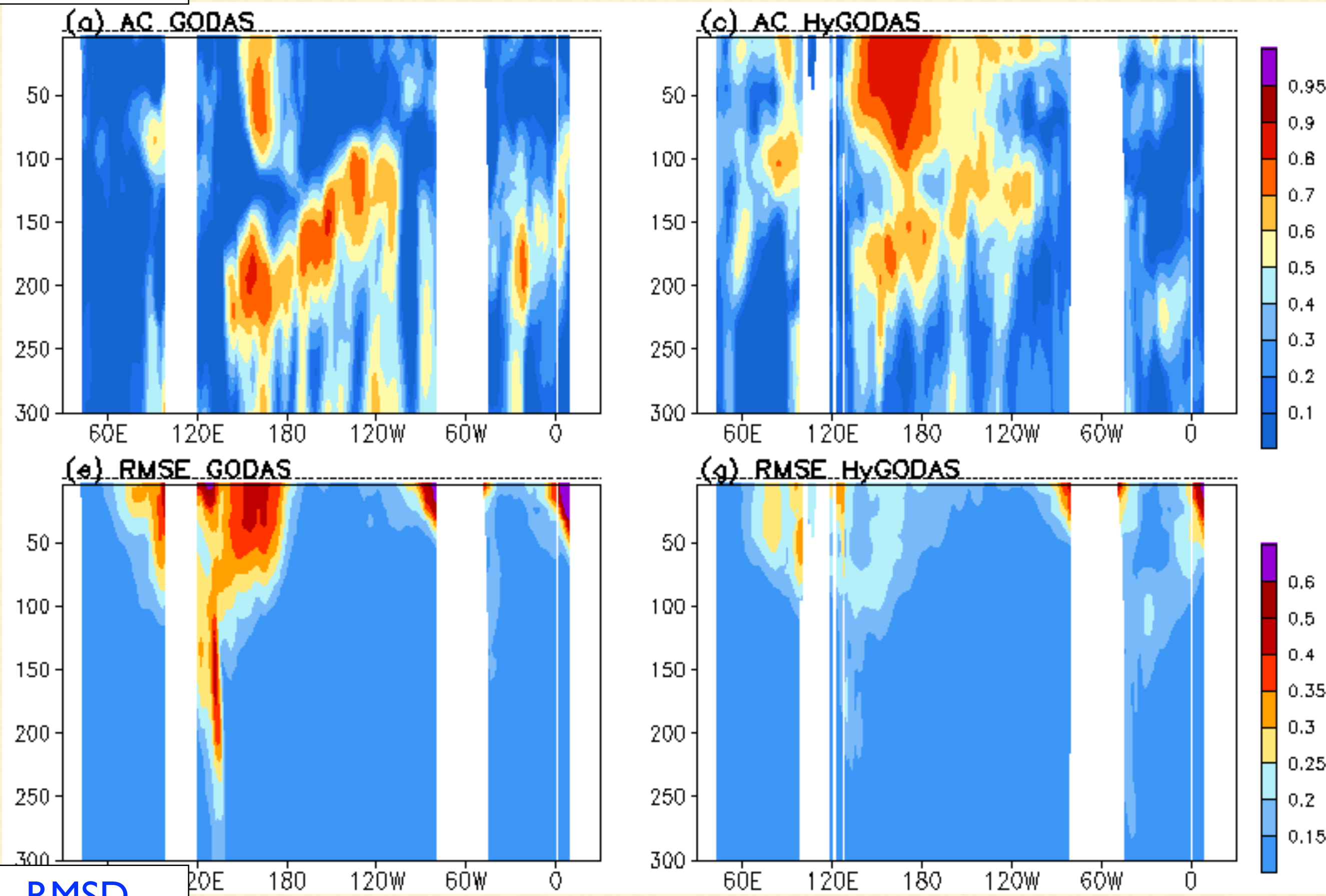
(e) RMSE GODAS

RMSD



(g) RMSE HyGODAS





TEMPERATURE

Summary of improvements over the operational 3DVar-GODAS compared to EN4 monthly analysis:

- Hybrid-GODAS increases Anomaly Correlations (ACs) and reduces Root Mean Square Deviations (RMSDs) of upper ocean temperature in the far western and eastern equatorial Pacific

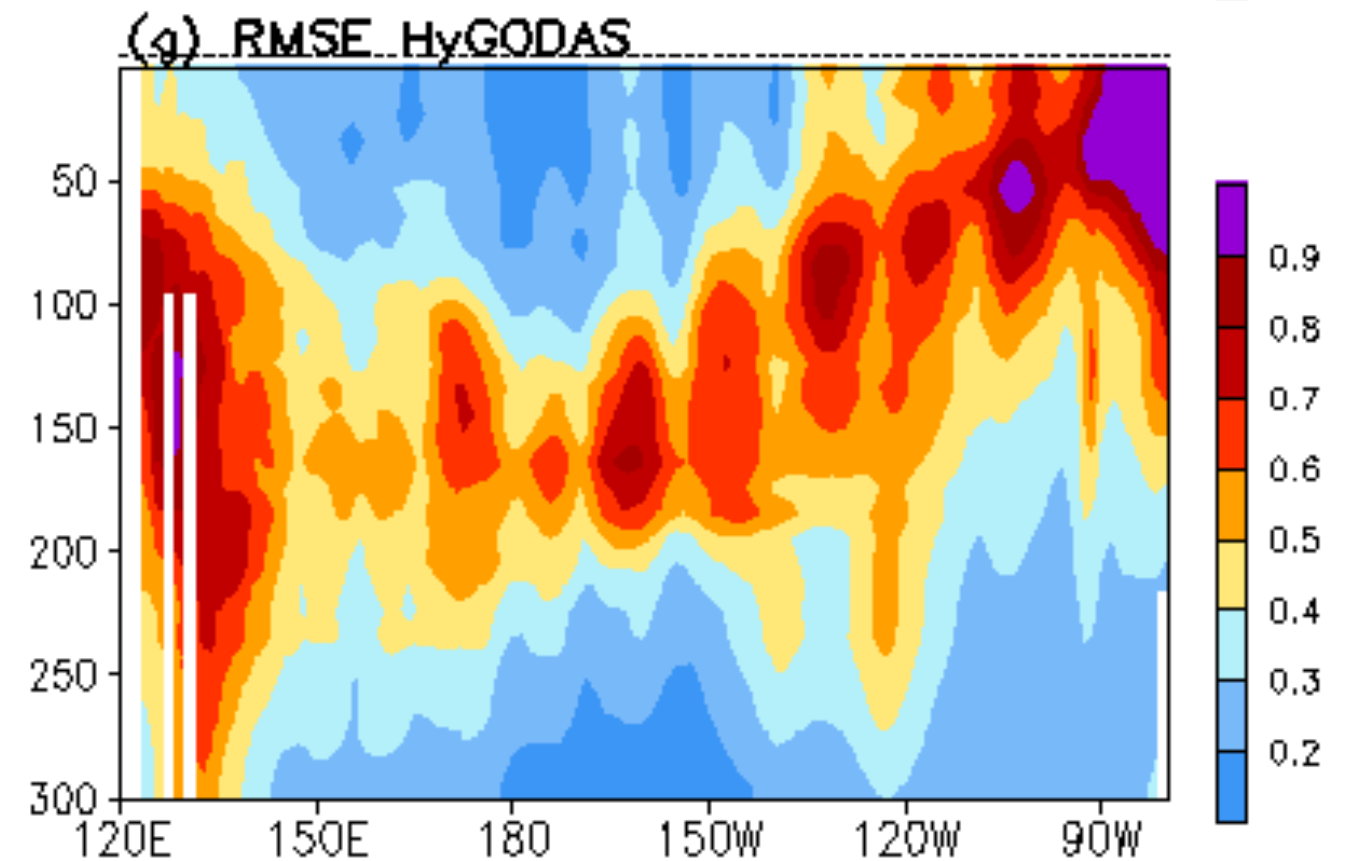
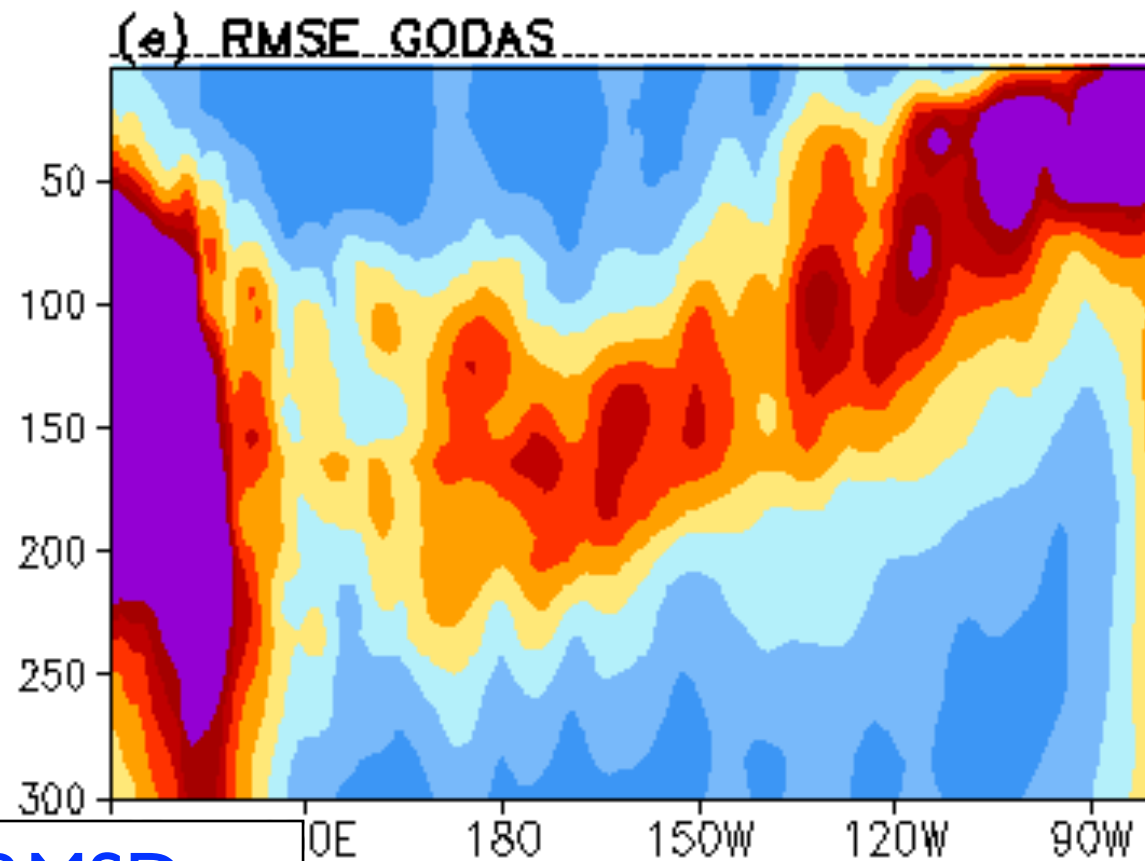
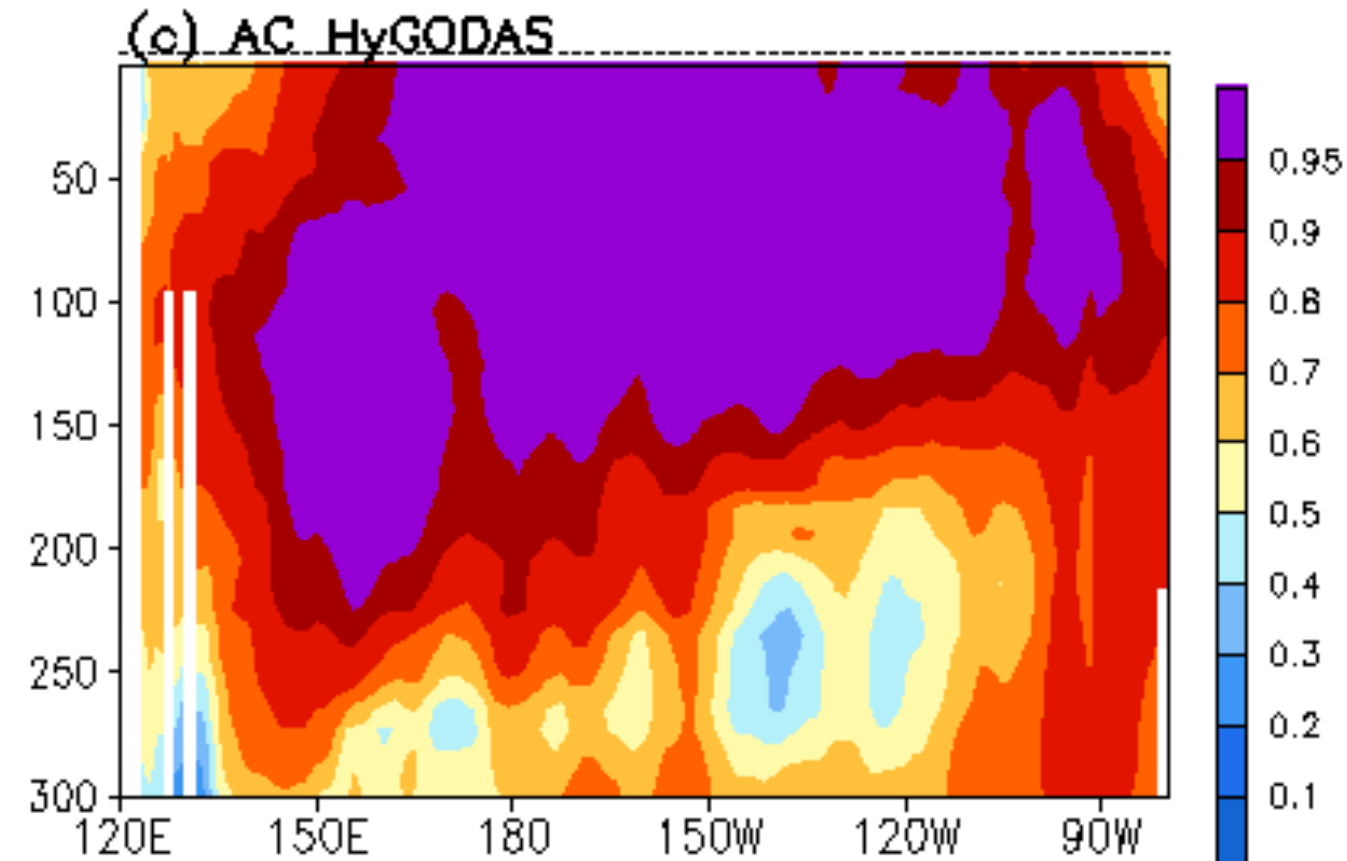
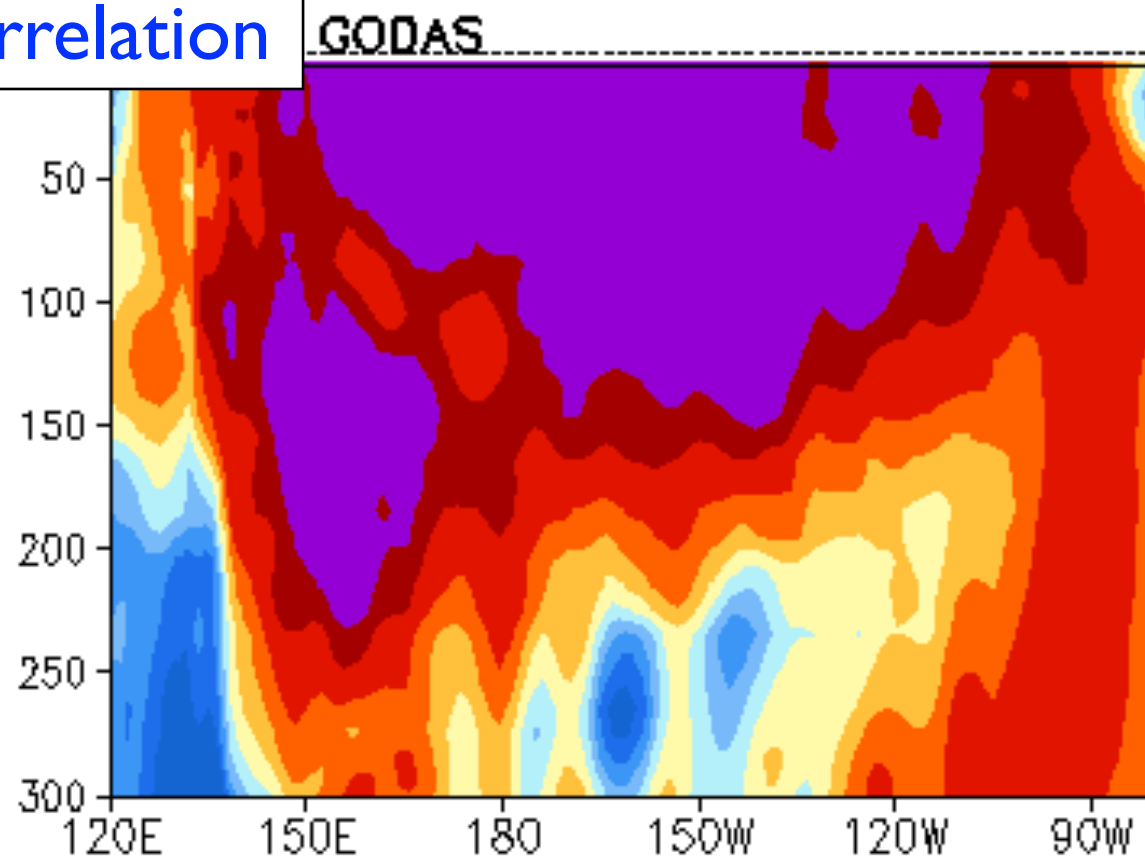
However,

- There are reduced upper ocean temperature ACs outside of the Tropical Pacific
-

Comparison with EN4 Equatorial Temperature (1995-2011)

Focus: Equatorial Pacific

Anomaly
Correlation

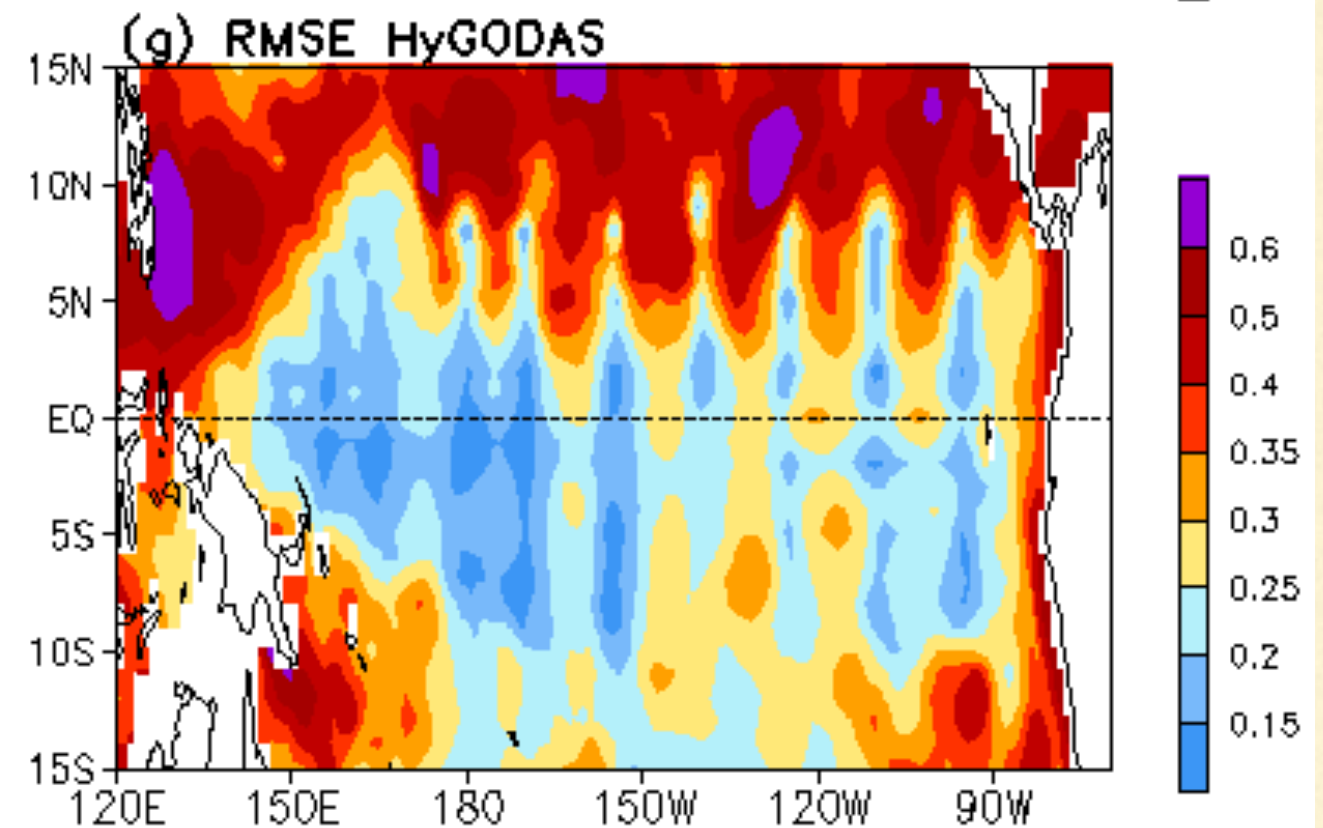
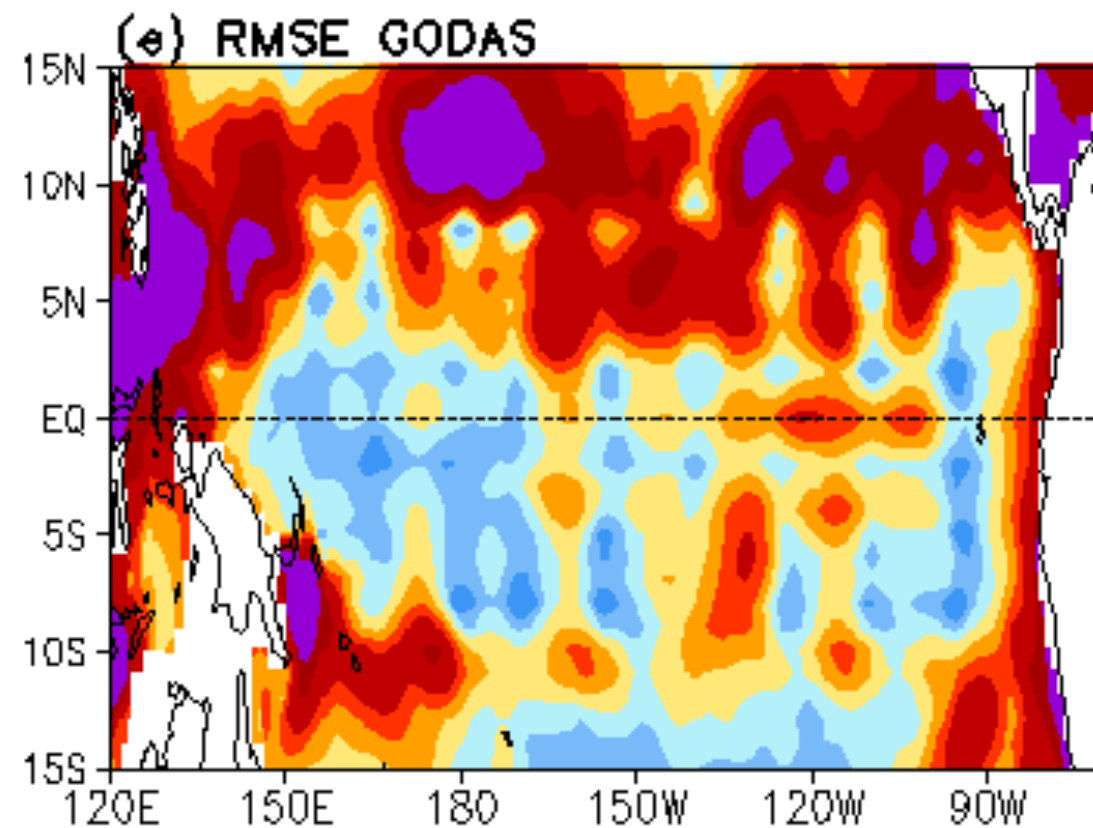
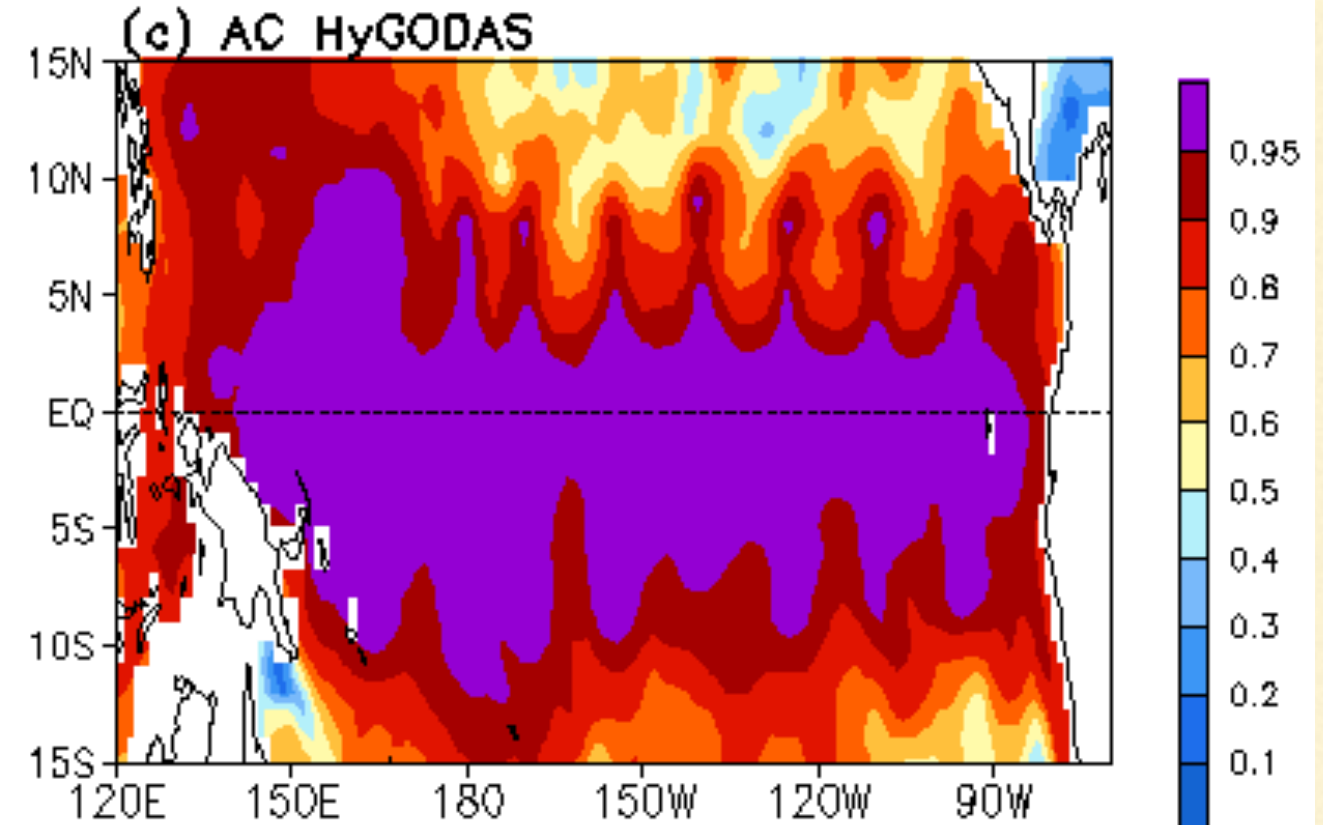
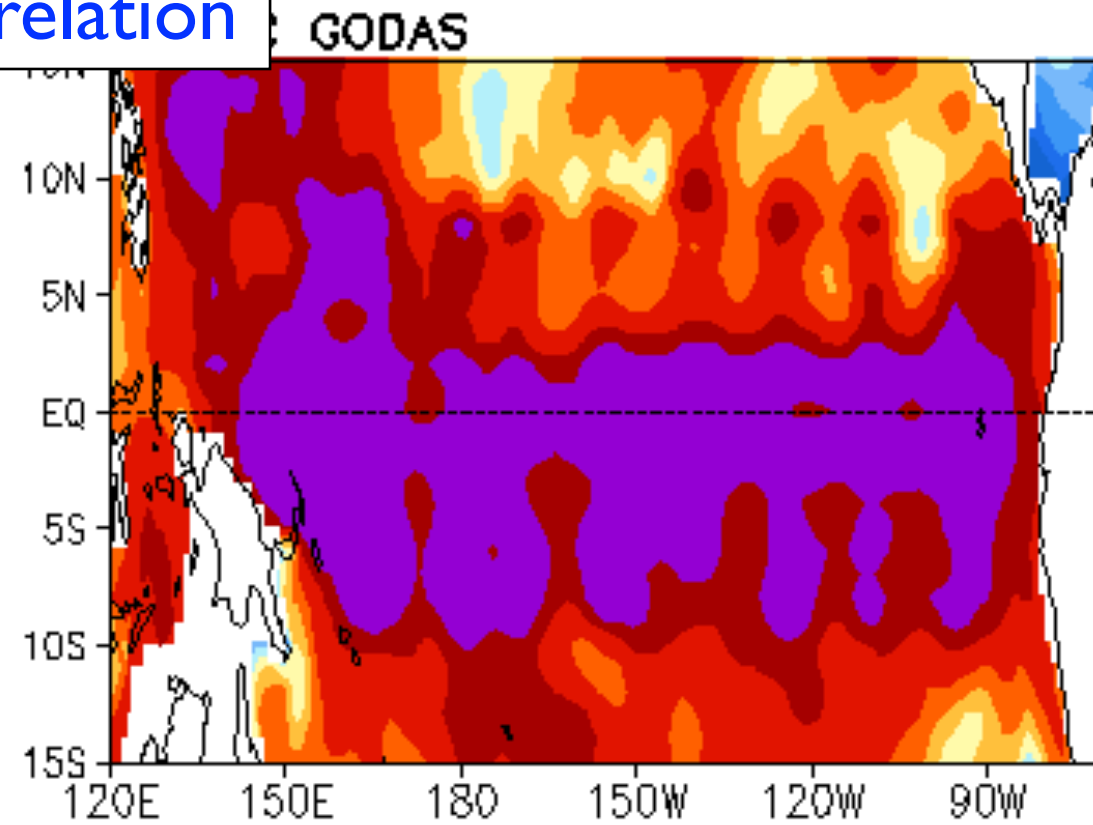


RMSE

Comparison with EN4 Temperature 0-300m (1995-2011)

Focus: Equatorial Pacific

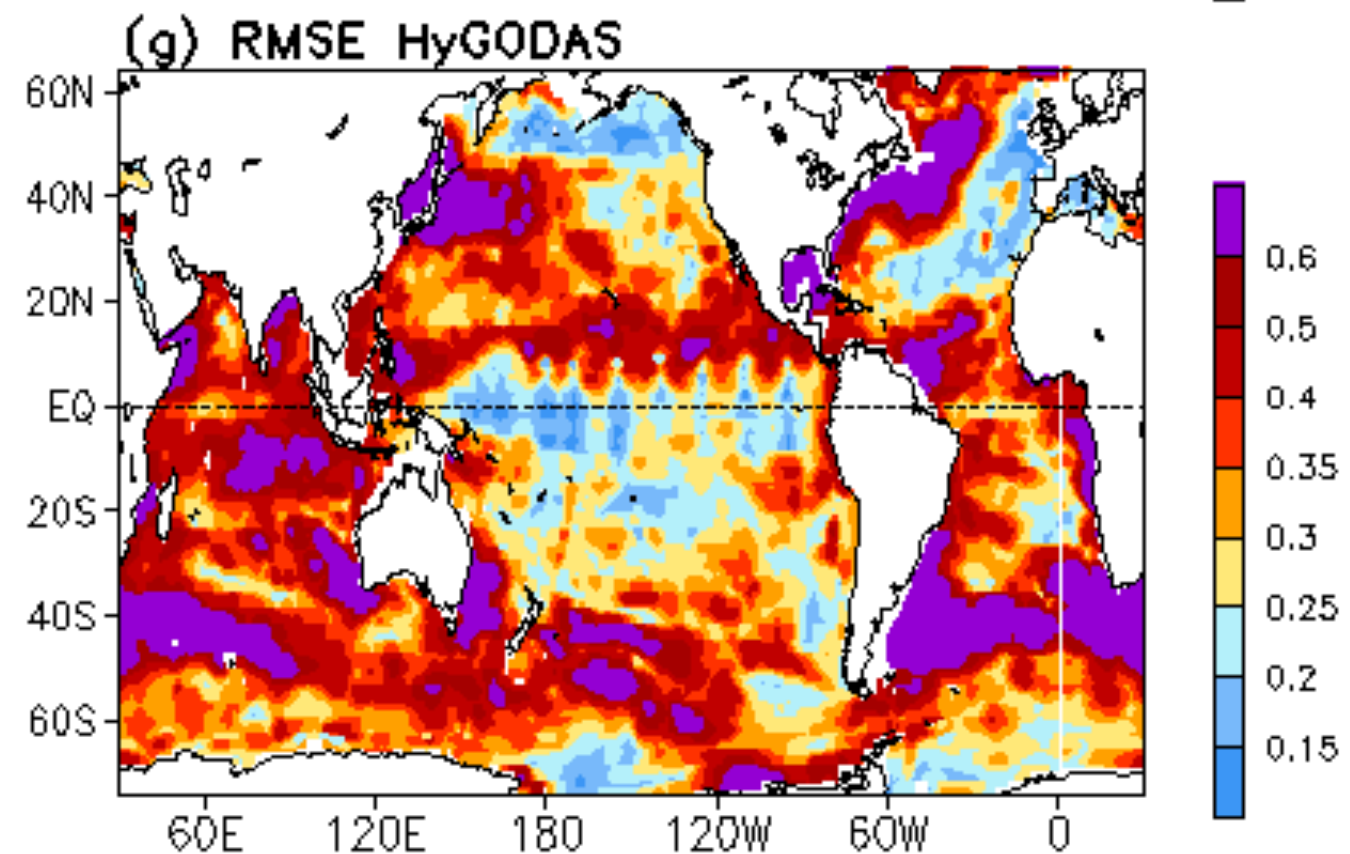
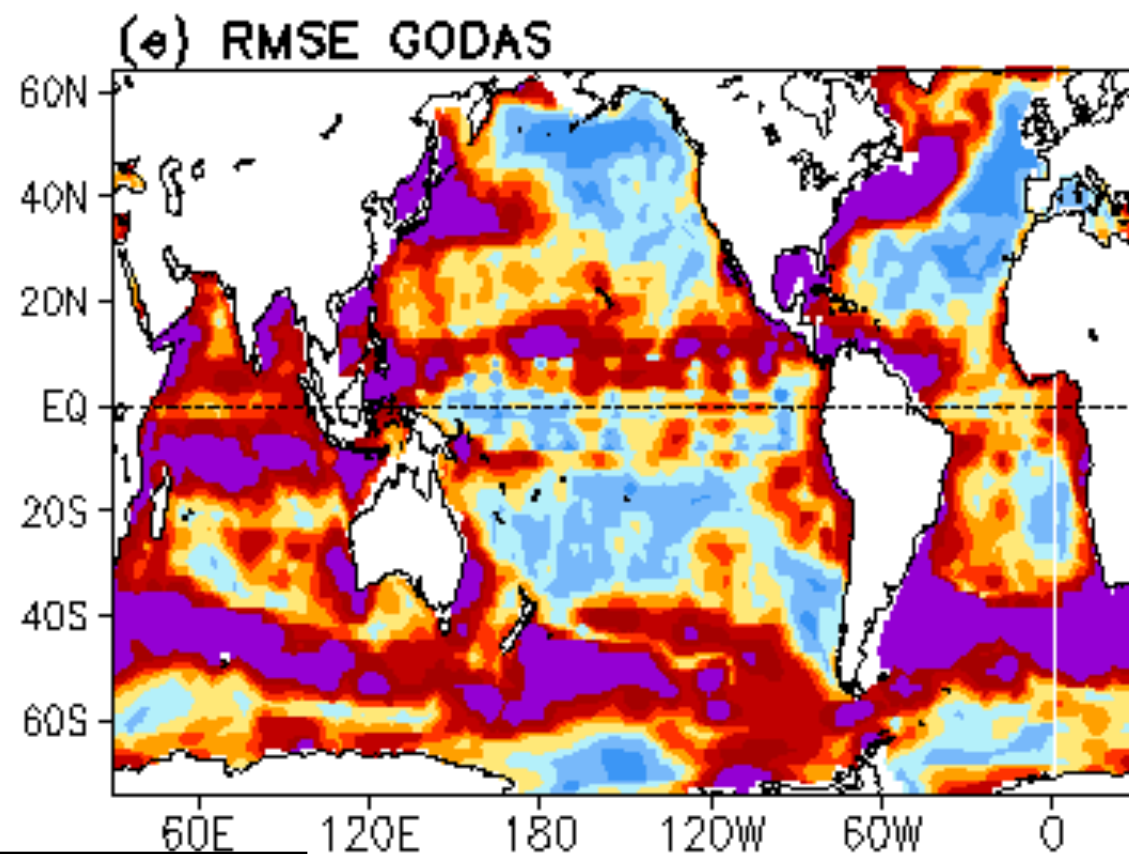
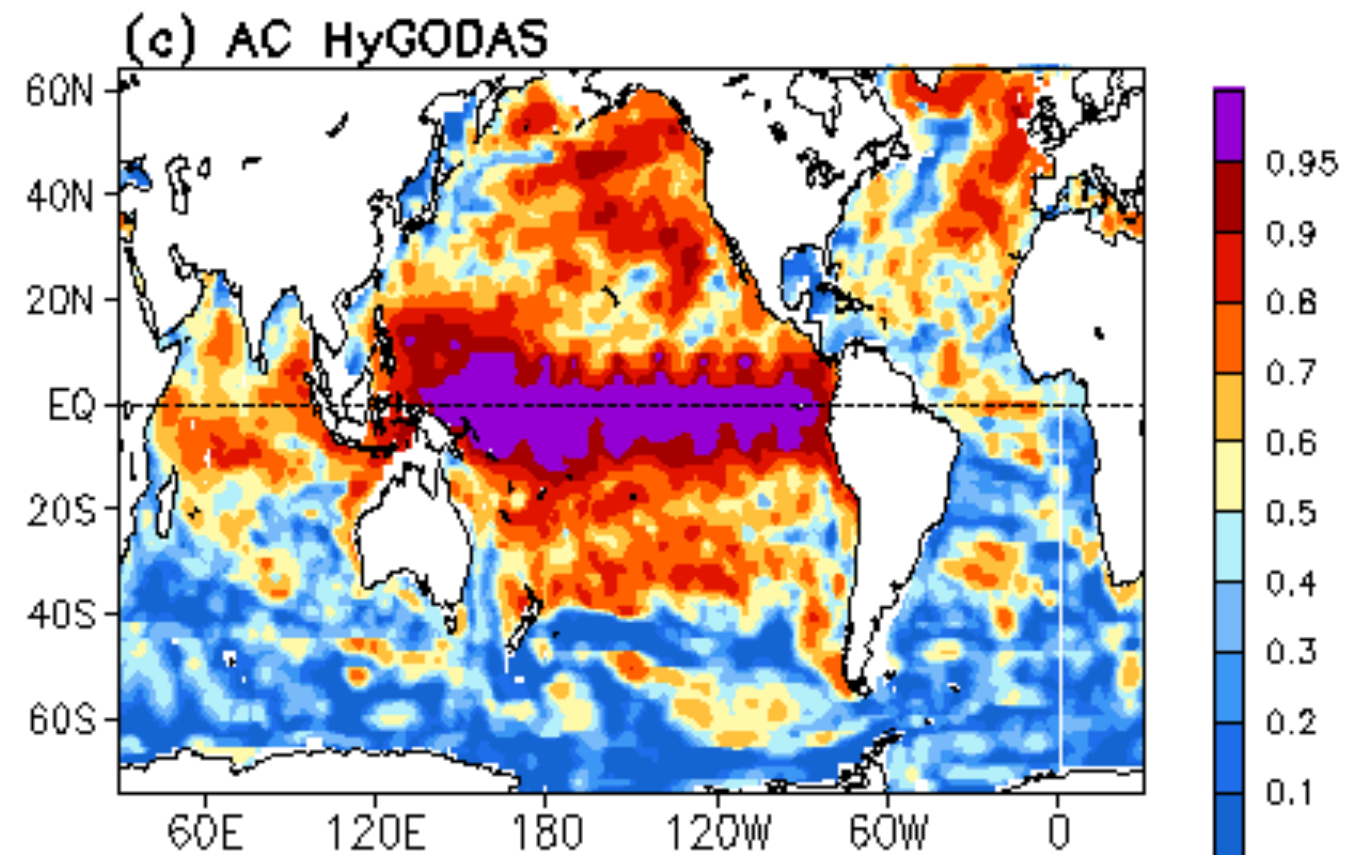
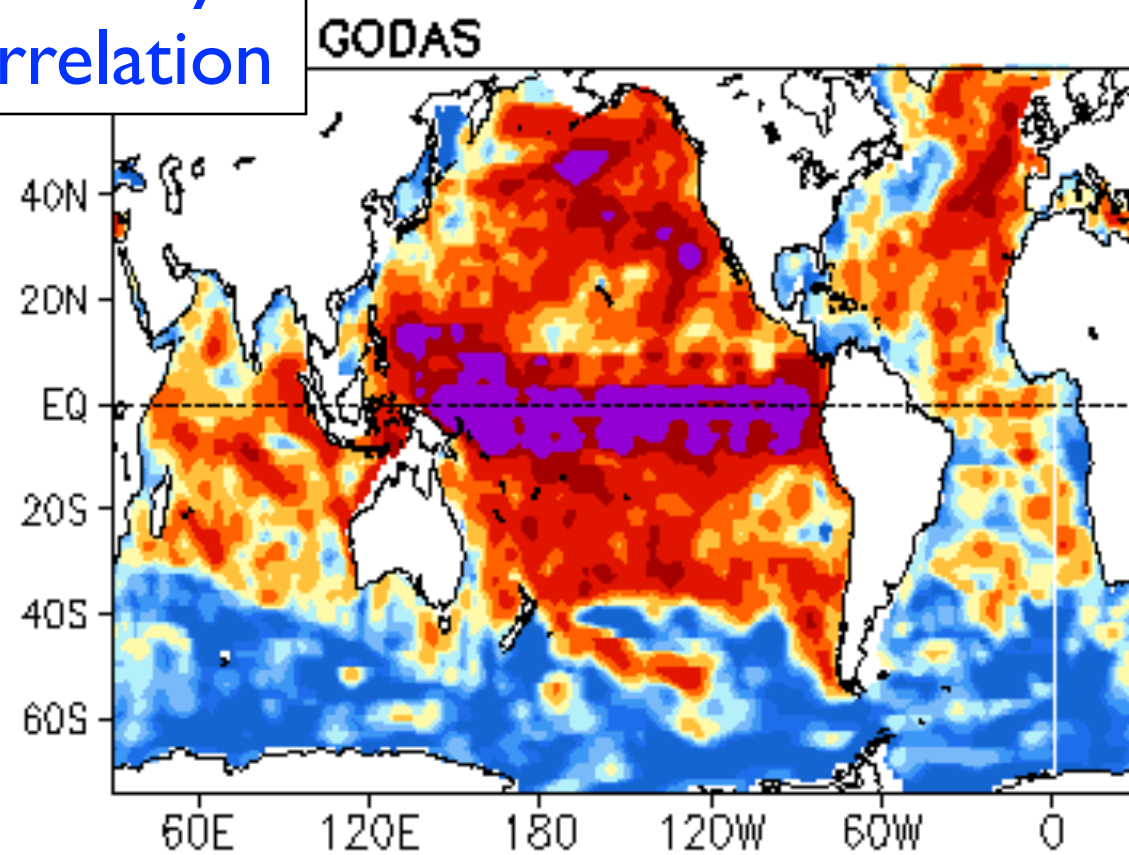
Anomaly
Correlation



RMSE

Comparison with EN4 Temperature 0-300m (1995-2011)

Anomaly
Correlation



RMSD

CONCLUSIONS

- The Hybrid-GODAS provides significant improvements over the current operational 3DVar-based GODAS.
- Possible degradation in Atlantic basin and equatorial Indian Ocean heat content (compared to EN4).
- Inclusion of satellite observations will improve upon this in situ assimilation baseline.
- Coupling with a high-res atmospheric ensemble will improve representation of surface forcing uncertainty.

